December 1955

NUCLEONICS

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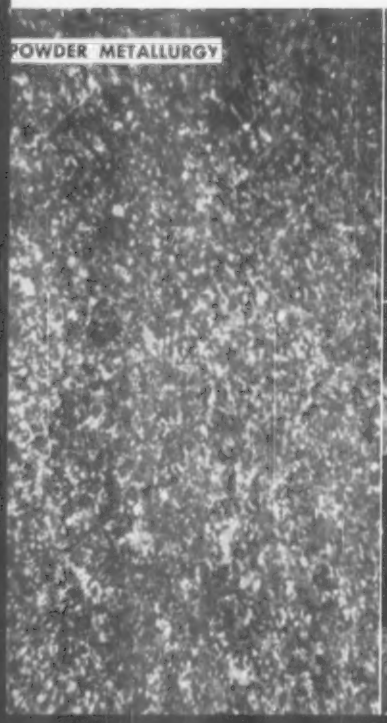

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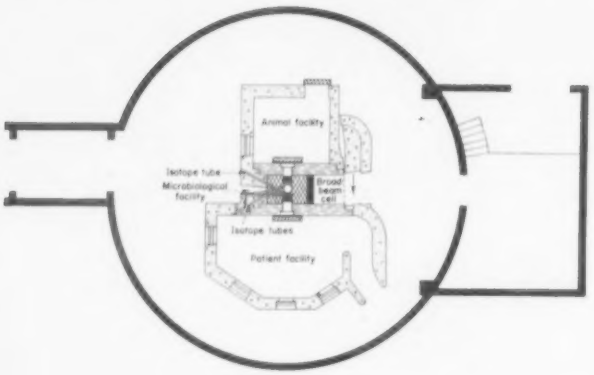

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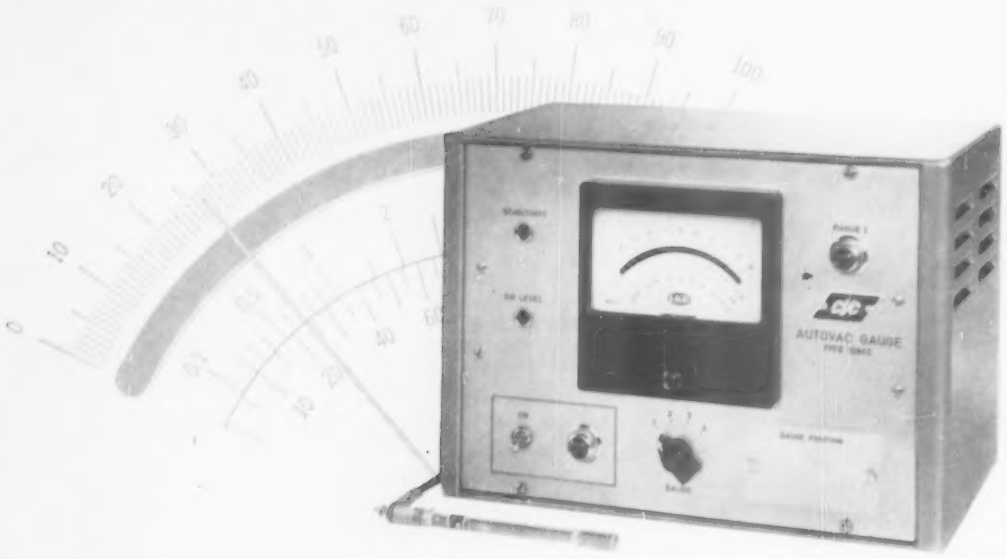

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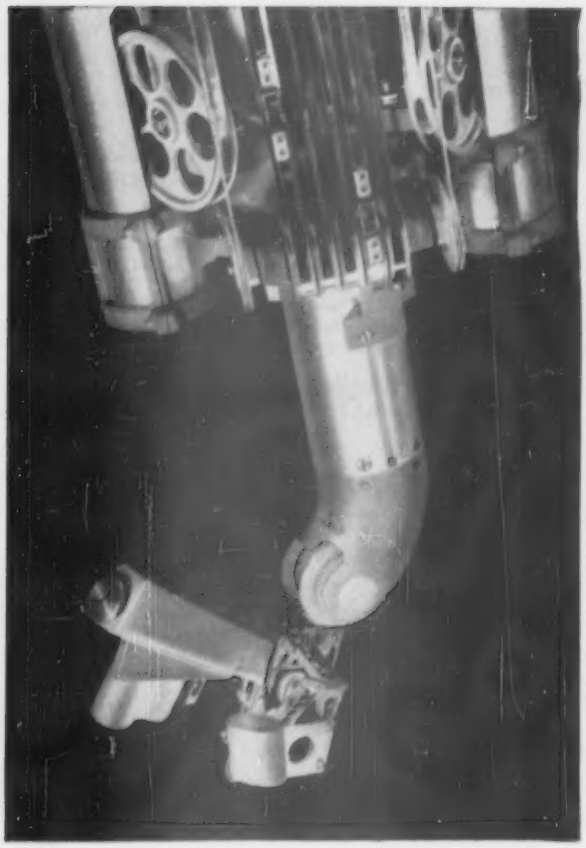

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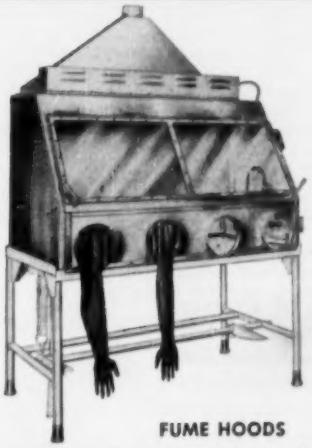

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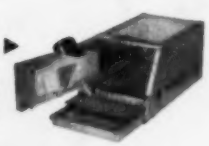

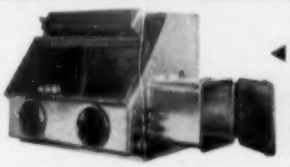

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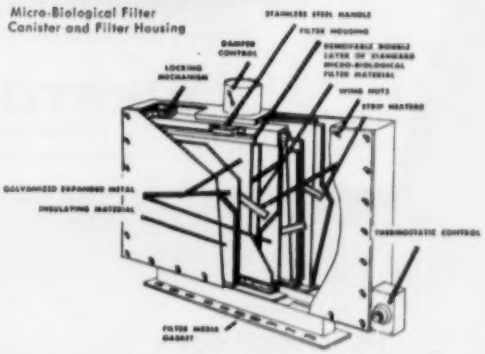

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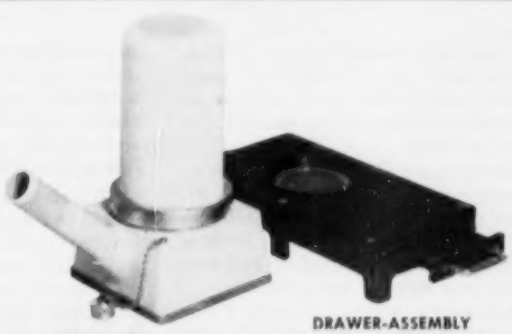

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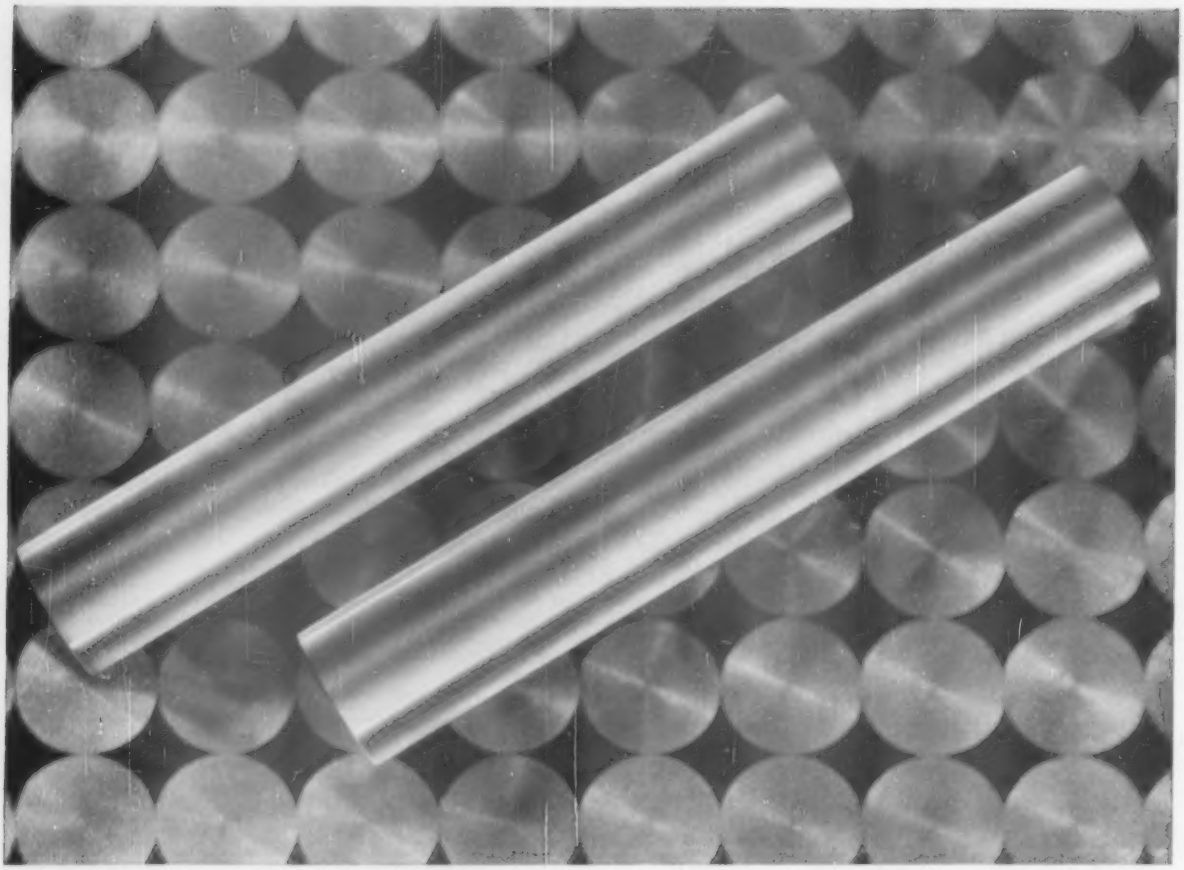

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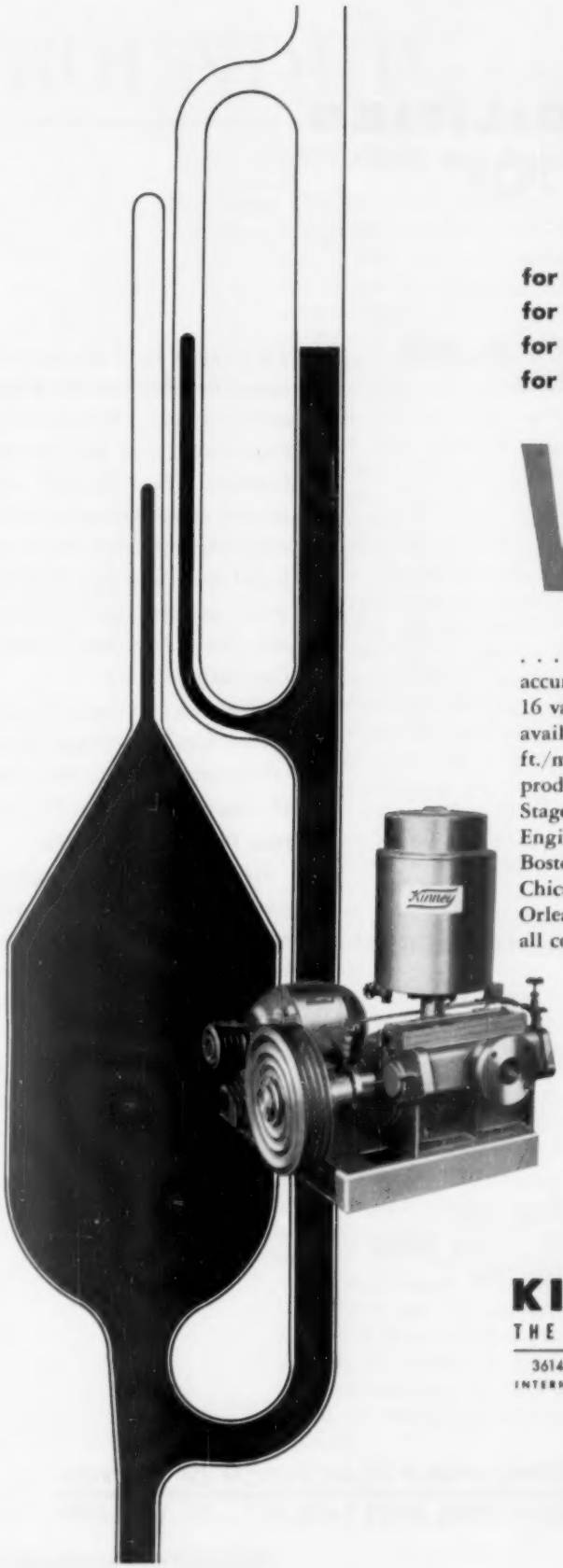

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ROUNDUP of Key Developments in Atomic Energy

LATE NEWS and Commentary

AEC Faces Hearings

With Congress due back Jan. 3, and the second annual "Sec. 202 Hearings" before the Joint Committee on Atomic Energy on the state of the atomic industry due to start within 60 days thereafter, AEC is working at full tilt preparing to put its best foot forward. (The report of the McKinney panel on the impact of atomic energy on American industry is to be submitted to the Joint Committee on Jan. 31, and it is unlikely that the main part of the hearings, expected to be based this year on the McKinney report, will begin before then.)

The regulations spelling out the application of the '54 atomic energy law to civilians, published over the past year in tentative form for public comment, will all have been issued in final form—so AEC expects—by the turn of the year, except one. That one, on radiation hazards, elicited more suggestions and criticism than any other; and because it affects so many groups, from radioisotope users to reactor owners, AEC's Division of Civilian Application will take all the time it needs to get it in shape.

Before completing revision of the regulations in the light of public comment, Civilian Application sought the "views and advice" of industry on policy matters. It called in representatives of industry for a second round of discussion. As in March, invitations were in four groups: to electric utilities, equipment manufacturers, chemicals makers, and research organizations. Among the examples aired of current thinking in AEC on issues outstanding were these:

• Licenses for fuel fabrication facilities may be eliminated, with only the mandatory licensing of fissionable material used at the facility retained.

• Conversion of 104 (research) to 103 (commercial) reactor licenses will not become a problem; a 104 license, once granted, will be renewed as such for the economic life of the plant.

• The reactor safeguards staff within the Commission is being groomed eventually to take over the routine reviewing of reactor hazards evaluation reports. This will permit the Rogers McCullough committee, a part-time, volunteer—and overworked—group, to revert to its originally-planned function as an advisory group on safeguards policy. Charles D. Luke has been shifted from director of the classification division to technical assistant to the director of Civilian Application on health and safety. Charles L. Marshall, deputy director of classification, moved up to head that section.

• In drawing up radiation safety codes, one objective of Civilian Application is to achieve uniformity of the various state rules and the federal rules that will be written, to prevent conflicts. To this end, twelve state public health or industrial hygiene officials were named by AEC as a board of advisers, to permit AEC to maintain closest cooperation with the states.

• As regards insurance, AEC is up in the air awaiting a report from its insurance industry committee, scheduled to meet this month. Three unknowns confront AEC: the maximum coverage that the private insurance industry can raise, the premiums it would ask, and the additional coverage deemed necessary. Until these are determined, the Commission cannot decide what additional legislation, if any, it should seek from Congress regarding power reactor liability. Industry is reported to have decided $30–$40-million is the most it can write. One opinion heard at AEC—although not necessarily the one that will prevail—is that any reactor not safe enough to require more coverage than that ought not be built.

While the equipment manufacturers were assembled, AEC reactor chief W. K. Davis seized the opportunity to ask for expressions of interest by industry in building a small pilot liquid-metal-fueled reactor (see p. 14).

Foreign Picture

On the international side, power reactor bilateral agreements involving exchange of classified information will highlight the coming year. None will be ready for submission to Congress when the session opens, but some will be laid before the Joint Committee before adjournment. For protocol reasons, names of the countries involved are still a jealously-guarded State Dept. secret. However there are not expected to be as many as there were research bilaterals this year. For one thing, the power bilaterals will not be standardized texts like the research agreements, but will be tailored to meet the individual circumstances of each country. For another, the main U. S. drive now is for implementation of the research bilaterals. It is felt there is little point in signing power bilaterals with countries obviously not in a position to do anything with them. Another consideration is the need for adequate security measures in the foreign country. Special legislation to satisfy AEC security standards may be needed in some countries (as for example was the case in Belgium), but not necessarily in all. Countries wishing to conclude power bilaterals may be well advised to review their security situation in advance, some AEC officials say.

Finally, there is this major question, one that is the main hold-up: the problems in making U. S. enriched fuel available abroad for power reactors. The two major problems are what quantities are to be made available for export, with a subsidiary question being the degree of enrichment (AEC appears ready to accept the conclusion of its reactor chief W. K. Davis that 10% enrichment is a reasonable maximum); and how to keep tabs on the possible production abroad of plutonium in U. S.-supplied uranium. While these problems are being worked out, possibly within the next two months, U. S. action on power bilaterals is stalled—or, as Commissioner W. F. Libby told NUCLEONICS, the situation is like "an engine idling."

Meanwhile, the government is seeking to spell out an exact formula for putting into effect the President's offer in June of half-price research reactors. It is now learned that there was no specific plan on this at the time the speech was made—e.g. whether aid would be given only on the cost of the reactor or also for the building and associated equipment. This is now being defined.

•

Fusion Secrecy

In October former AEC Commissioner Henry D. Smyth told an NICB conference that fusion-for-power has "no significant military importance" and should be declassified. Lawyers close to the subject say flatly that it would be illegal under the '54 to classify it if indeed it has no military value. Commissioner Libby, however, indicated to NUCLEONICS that the AEC does not share Smyth's conclusion on this point: "If you assume [Smyth's thesis]—and I won't even discuss that—*if* you assume that, I would declassify it," to hasten progress.

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Fuel Element Order to B&W

Babcock & Wilcox grabbed the brass ring on AEC's plan to get out of the MTR fuel-element manufacturing business. One of about 12 bidders, B&W got the contract to make a year's supply of U-Al plate assemblies, on a fixed-price—not cost plus—basis. AEC asked for bids in August, got them in October (NU, Oct. '55, p. 10), and decided last month. A factor in the decision, it is believed—in addition to B&W's attractive offer—was AEC's desire to sponsor the use of a private plant for the job; B&W's $2-million Lynchburg, Va., plant, now going up, will be the first privately-owned factory devoted to and designed for nuclear-fuel fabrication. B&W hopes to start production between March and June—April is the target; the unknown factor is delivery date of a rolling-mill coming from a flood-struck plant in the Connecticut Valley. The contract probably looms larger in prestige than in profit; the company will also learn how to make fuel elements cheaply, of a type to be used in research reactors the world over.

European Atomic Pool Plans Advance; Carry a Challenge to U. S. Domination

Plans for a Western European atomic pool that would make of the six coal-steel pool countries an independent, first-rank power in peaceful nuclear industry progressed last month in Brussels. The plan represents an urgent desire for revolt against existing tight U. S. control over enriched U supplies, and the limitations on isotopic concentration and on the use to which enriched fuel may be applied.

Euratom, as the proposed European Atomic Agency would be called, is being organized by the six Schuman Plan countries—France, Germany, Italy, Belgium, the Netherlands and Luxembourg. Britain has taken an active part in the negotiations, and a report of staff experts of the Six expresses the hope she may eventually become a participant. The plan was first seriously broached at the Messina integration conference in June.

The report, completed last month in Brussels, contains the recommendations of a team of inter-Government experts who worked out the plan's details. They are now being considered by a committee of heads of delegations under Belgian Foreign Minister Paul-Henri Spaak, who was to have reported to the other five foreign ministers after the French parliamentary elections originally scheduled for June. The fact that M. Spaak at month's end called a meeting of the six foreign ministers, without waiting for the date of the French elections to be set is evidence of the urgency of the matter in his mind.

Not all M. Spaak's countrymen share this view, however. Many Belgians most intimately connected with the country's atomic energy program, both in industry and government, express disinterest in atomic integration and a feeling of independence, based on Belgium's strong raw materials position.

In the U. K., likewise, the opinion is often heard that while Britain can be counted on to cooperate closely with the new agency, "for Great Britain to join an essentially European organization as a full member would not be in keeping with her obligations to Commonwealth countries."

Euratom's cost, as projected in the staff report, would involve about $220-million spread over 5 years, of which $70–$80-million will be operating cost. This is apparently in addition to expenditures on coordination and education including liaison with the European Nuclear Research Center (CERN) at Geneva and the future U. N. atomic agency, and establishment of a specialist school to train personnel in raw material prospecting, nuclear engineering, production and use of radioisotopes, and production and reprocessing of high-purity nuclear fuel. For this, $20-million a year in operating costs is contemplated.

Coordination will extend not only to national research and development programs but also to unification of regulations for public health and protection of personnel.

Euratom's first main task will be the promotion—perhaps even actual ownership—of a number of common installations. Among these, highest priority is assigned a U^{235} separation plant—so high that many are urging that plans for it go forward at once without even waiting for signature of the pact establishing Euratom. They plead the importance of moving in on atomic industry before the vested interests are too firmly entrenched; also, the need to anticipate a possible U. S. cut-price offer (as with D_2O); finally, the possibility that U^{235}, so important today, may be less so in a dozen years' time. Therefore the big isotope separation plant will have to be written off as quickly as possible, and it is desirable to give it maximum useful life. Judging from cost estimates, the separation plant contemplated would be on a much smaller scale than Oak Ridge, for partial enrichment only.

Other common installations contemplated now include a measurement and research center; a chemical reprocessing plant to remove Pu and unconsumed U; an isotopic separation plant for D_2O; and the building of prototype reactors—fixed and mobile, research and power.

It is suggested there be a six-nation pool of nuclear patents, and that any discovery made in a common installation be treated as common property. Euratom may also be empowered to buy patent rights from nonmember countries.

Second big job for Euratom is seen as ensuring the supply of nuclear fuel to all member states at a common price. The experts contend this is what will give coherence to the plan. There is some difference of opinion as to how far the Euratom powers should go, but it is agreed the minimum terms would permit no member country to buy nuclear fuel for scientific or industrial purposes except from Euratom itself. This would rule out independent buying, but would leave the integrated French system to look after its own needs through its own AEC.

The form of the Euratom organization will be decided at ministerial level, with the ultimate sanction of the parliaments of the six powers. It is suggested that there be a Board of Commissioners with responsibility for Euratom policy; but the ministers will have to decide whether the commissioners will be representatives of their national governments, or—like the 9 members of the High Authority of the Coal and Steel Community—supranational beings who have forsaken their nationalities for the higher duty of serving the collective organization. Responsible to the Commissioners, in any case, will be a Council of Specialists who will be the real brains of the agency. One of the Commissioners will act as managing director to ensure the dispatch of day-to-day business.

The experts' report makes it quite clear that—though the plan will have to deal with government agencies that may, as in France, be vested with full ownership and monopoly powers—the aim is to encourage private industry.

Belgium Buys Westinghouse Reactor to Light World's Fair; 11.5-Mw Plant is First Nuclear Power Unit Sold for Export

Belgium got the first American power reactor to be sold for export, and Westinghouse made the first sale. The 11,500-kw pressurized water reactor, first power pile to be exported anywhere in the world, is to be completed at Laeken, a suburb of Brussels, in time to supply almost one-third of the power load that will be required by the Brussels World's Fair opening April 1, 1958. To meet this schedule, all components

must be on site by December 1957 at the latest; Westinghouse is aiming for August or September.

Price of the reactor, according to Jean H. Van der Spek, manager of the purchasing syndicate, will be between $4.6 and $5.7-million—that is, between $400 and $500 per installed kilowatt. This is between 2 and 3 times more than the cost of conventional power in Belgium today; however the reactor vessel will be engineered to take different types of cores, leaving room for operating-cost improvement as better fuel elements are developed.

No government money is involved in the plant's financing; all the capital is being put up by Belgian private interests, organized in two syndicates. One (SEEN) is a group of 20 of the country's biggest industrial concerns formed to develop atomic energy for industry; the other (SYCA) represents electric utilities.

Westinghouse will build the turbine as well as all primary components, but will share with Belgian manufacturers the making of apparatus for the secondary and auxiliary systems. Belgium will supply the generator and perform civil engineering work. Gibbs & Hill, Inc., of New York, has been chosen by Westinghouse as engineer-constructor because of its experience in powerplant construction abroad. Westinghouse will provide training facilities in this country for operating personnel of the Belgian group, and will also lend staff engineers and scientists to insure that the plant is placed in proper operation.

"The Fair is not the main reason for the plant," Mr. Van der Spek declared, but rather Belgium's determination to seek a top rank in applying the atom to industrial uses. "There is no substitute for practical operating experience in the field of atomic power," he said. "At the same time, we are interested in showing in Belgium what atomic energy can do."

Consequently an exhibit hall located adjacent to the reactor during the Fair will show visitors how the powerplant works. After the Fair, current produced will be fed into the Belgian national grid.

The plant's 11,500-kw rating represents the level at which it can operate steadily, according to Mr. Van der Spek; it will be capable of appreciably higher output for two or three hours at a time.

Following the recent American trend, the entire primary—including reactor, steam generators, pumps and high-pressure auxiliary equipment—will be enclosed in a vapor-tight container, so as to prevent the

Washington Report

The Maritime Administration's recent action in calling for prices on nuclear propulsion plants for two merchant ships—one, a tanker, to be in operation by June 1959; the other, a slightly different design, by June 1961—has added another effort to get an atomic-powered merchant ship built.

The Maritime Administration says the tanker will shape up roughly at 20 knots and 38,000 deadweight tons—about the same size as conventional tankers, but about 2 knots faster. It would develop 20,000 shaft horsepower with a reactor generating from 45 to 75 Mw of heat.

Although little has been said publicly, thinking at Maritime is that a tanker would be the best type to start out on with atomic power. Reason is that all space saved with the nuclear power plant could be converted immediately to paying cargo. With a dry-cargo ship this might or might not hold true, as they don't always sail with a full load; tankers usually do.

But outlook for Maritime's tanker is not good. Congressional committees are a bit miffed at the proposal. They say the Maritime tanker, calling for a Nautilus-type reactor, adds nothing new to the hassle over an atomic merchant ship, and that it would do little to advance the practical use of nuclear power in merchant ships. This point caused all the fuss in Congress last session. Also, the dates Maritime gave for putting the ships in operation—1959 and 1961—means using a Nautilus-type reactor; experts last session talked of 8 to 10 years needed to develop a nuclear reactor that would approach commercial feasibility for merchant ships.

Another reason Maritime's tankers are getting off to a bad start is the dispute over who is to be boss on atomic ships. Last session Rep. Bonner's House Merchant Marine Committee and the Joint Atomic Energy Committee were at odds over this; both wanted to be on top. Now neither side is happy over Maritime branching out on its own without first consulting Congress.

Defense research projects are being conducted on nuclear propulsion for surface ships—notably the Newport News Shipbuilding-Westinghouse Large Ship Reactor project at Arco—but they do not tie in directly with an atomic merchant ship. For although 24 companies* doing such research have been asked to give prices on Maritime's tankers, and there is undoubtedly a certain amount of overlap, there still remains a big difference between putting atomic power in a large aircraft carrier—Navy's plan—where defense use comes first and cost later, and in a merchant ship that must pay its way.

A whole fleet of bills for an atomic-powered merchant ship were left hanging in Congress when it went home this fall. "Peace-ship" bills to give the President a chance to show off peaceful use of atoms were left bottled up in the Joint Atomic Energy Committee; Rep. Bonner's bill to build two ships, one "peace," the other a commercial merchantman, passed the House but is now hung up in the Senate Interstate Committee; and the third bill for a straight commercial ship was left on the floor in both the Senate and House.

Chances look good for Congress to approve an atomic-powered merchant ship next year—one that will be commercially feasible. But if action comes it will probably be on an existing bill, and Maritime's latest efforts will get little attention—even though Maritime says its tankers could first be used to show off atoms and later converted to merchant use.

* The companies asked to give price estimates on the A-tanker are: Allis-Chalmers; Alco; AMF Atomics; American Turbine Corp., Babcock & Wilcox; Bechtel; Bethlehem Steel Corp. (Fore River Shipyard, Quincy, Mass.); Chrysler Corp.; Combustion Engineering; De Laval Steam Turbine Co.; Ford Instrument Co.; Foster Wheeler; General Dynamics; General Electric; Glenn L. Martin; Newport News Shipbuilding & Drydock; North American Aviation; Westinghouse; Avco Manufacturing Corp.; Kaiser Engineers; Ingalls Shipbuilding Corp.; General Motors (Cleveland Diesel Engine Division); Nordeberg Manufacturing Co.; American Radiator & Standard Sanitary Corp.

release of radioactivity even in the remote event of a leak in the primary system. It is said that a combination of confidence in the safety of the system and the high probable premium rate of insurance coverage has caused the Belgians to plan to carry no insurance on the plant.

Belgium will supply natural uranium to the U. S. AEC for enrichment, and Westinghouse will fabricate the fuel elements from uranium enriched to less than 10% supplied by the AEC.

The life of the first core is expected to be from 8,000 to 10,000 hours at full load, attaining 10% burnup. Spent fuel elements will be removed and handled under water, and eventually returned to the U. S. for reprocessing, at least at first; later Belgium may build her own reprocessing facilities. If the original U were to be supplied by the U. S., the terms of the U. S.-Belgian bilateral agreement would have made it mandatory for the fuel to be reprocessed in the U. S.

The reactor was conceived and designed as a straight power reactor, so there will be no experimental facilities, such as test holes, that would conflict with its primary purpose, Mr. Van der Spek indicated. However it will be rigged with "all kinds of special facilities and instruments" for measuring its operating characteristics as a power producer.

Westinghouse officials objected to a comparison of the reactor's design with that of the Shippingport PWR. While both belong to the same family of reactors, the Belgian design is a step forward from Shippingport and makes use of lessons learned there, they stressed. The new, smaller reactor will differ considerably in pressure characteristics, core design, and the use of slightly rather than highly enriched uranium.

It has been said that Westinghouse is aiming at the sale of ten reactors of this design, in order to spread development costs, and that its success in this endeavor may be reflected in the final price of the Belgian pile. One other sale of such a reactor by Westinghouse, to Fiat of Milan, apparently awaits only the conclusion of a power bilateral between Italy and the U. S. In addition, William E. Knox, president of Westinghouse International, admits to "a number of active negotiations at the present time," but beyond saying that Sweden is involved in one of them, will not make any announcement yet.

About the Industry

Widespread industry plans to increase zirconium production and handling capacity came to light last month. A two-day zirconium conference sponsored by the Atomic Industrial Forum brought to New York 125 key figures in the metal industry to discuss both processes and sales.

Carborundum Metals Co., at present the only producer of low-hafnium reactor-grade Zr, is supplying 200,000 lbs annually to AEC plus smaller amounts to private reactor programs here and abroad. It is undertaking an expansion that will give it a capacity at least 325,000 lbs per year by Feb. 1, 1956. In addition it is planning a further expansion "whereby we can double this new capacity by the fall of '56 and provide any required capacity by July 1957."

Allegheny-Ludlum Steel Corp. with a 17,000-lb monthly melting capacity now and 25,000 lbs by year's end is now installing "the industry's largest Zr-melting furnace." It expects a 25¢ per lb reduction in ingot price.

Bridgeport Brass, which until now has been doing mostly research in Zr, hopes to get a vacuum-annealing furnace early in 1956 to complete existing drawing, pickling and extruding facilities.

National Research, manufacturer of Zr melting equipment, now has available vacuum furnaces with a melting capacity of 80 lbs but is "confident capacities up to 2000 lbs can be furnished on order."

Even the Bureau of Mines is installing in its Albany, Ore., research station a new furnace that will increase the maximum size of Zr castings from 150 to 250 lbs.

Dr. R. C. Dalzell of AEC pointed out that the Commission's firm requirements for Zr had risen in four years from 175,000 to 900,000 lbs annually. "I have no hesitation in saying this won't be enough and that before 5 years are up we will be seeking additional supplies," he predicted. AEC is now seeking a second prime producer of reactor-grade sponge, expects three new processes (other than Kroll) to be perfected commercially. It also sees a "radical reduction" in cost ahead.

Attacks on the radiation health problem through chemistry were also foreshadowed at the zirconium conference. A speaker reported that "certain zirconium chemicals are now under development for treating animals subjected to plutonium ingestion. By injecting Zr salts into animals within an hour after the Pu gets into the blood stream, the Zr salts decompose and soak up the Pu. Half of the Pu present is expelled within a day. The Pu remaining in the bloodstream is diverted from the bone to other tissues where its removal is accomplished by chelating agents."

AEC revised its bid to purchase uranium salts from industry. Liberalizing the terms of its call last month (NU, Nov. '55, p. 19) for U concentrates—made as "another step in the Commission's efforts to expand the scope of private participation in the atomic energy program"—AEC gave industry 6 months more to prepare proposals and 9 more to commence deliveries. It also downgraded from secret to confidential the specifications for UF_6, matching those for UF_4 and UO_3. An orientation meeting for cleared industry representatives has been set for Dec. 8 by the Division of Production on policy considerations and a general description of processes currently used by the Commission including related capital and operating costs.

ROUNDUP

First U.K. Atomic Report Hits Dearth of Skilled

The shortage of scientific manpower, already causing increasing anxiety in this country, is the salient theme running through the first annual report of the United Kingdom Atomic Energy Authority.

The 35-page report for the year ended March 31, 1955 covers the take-over on Aug. 1, 1954 by the new Authority of the existing program and establishments from the Ministry of Supply.

It reveals that the A.E.A's fiscal '54–55 expenses amounted to £53.7 million ($150.3 million) as against a '55–56 budget of only £50.6 million ($141.6 million). It reviews the isotope supply program (£450,000 ($1.3 million) worth sold in the year ending March 31, 1955). It gives some details on the two new research reactors being built at Harwell: Dido (ex-E. 443), a heavy water moderated and cooled, highly enriched U-Al alloy fueled, high-flux (10^{14} n/cm²/sec) pile to be used in souping up the Calder Hall design for the power program; and Pluto, basically the same but with redesigned experimental facilities for extensive materials testing. (A.E.A. is helping Australia build a Dido of her own.) Then there is Leo (Low Enrichment Ordinary water), a design study for a pressurized water reactor using—like Con Ed—a thermal-fueled superheater. English Electric Co. and Babcock & Wilcox of England are collaborating on this study. The report also reveals continued British interest in cermets—metal-ceramic mixtures—as solid fuel element materials: "interesting possibilities are uranium-thoria, silicon-uranium oxide and uranium-uranium carbide."

But the angle that hit the English press as a sensation was the shortage of skilled scientific manpower and the possibility it might seriously retard the entire atomic program: "the project has been expanding at a rate which few, if any, industrial enterprises would consider feasible; . . . the principal threat to the fulfillment of these programs in accordance with the timetable is the lack of skilled manpower. Her Majesty's Government have never hesitated to furnish the money needed . . .; material shortages have never been insuperable; but the difficulty of recruiting and retaining sufficient skilled scientists, engineers and craftsmen has been acute throughout the ten years of the project and shows no signs of becoming easier." The report describes the "great deal of effort" the A.E.A. devotes to recruitment; nevertheless it finds two conclusions unavoidable: a "serious national shortage of most types of scientists and engineers and of many technical and craft grades," and that A.E.A. is handicapped in not having "the same freedom of movement as industry in the matter of salaries." Worst of all, is the "difficulty in recruiting the younger engineers and technicians who are needed to form the base of the pyramid today and to provide the leaders in years to come."

"The development of atomic energy is unique in the variety of specialized skills which it demands," the report says, adding frankly, "This demand is not at present being met."

Reactor News

Holyoke, Mass., seeks reactor. The college town on the Connecticut River is one of the first to make known it is planning to bid in the second round of the AEC's power demonstration reactor program. The city's Municipal Gas and Electric Department has already formed a committee to draw up a proposal. North American Aviation officials have conferred with the city utility, which operates both steam and hydro plants as well as distributing natural gas. The municipal utility is already an access permit holder.

APDA reports on test facility progress. Construction of components of Atomic Power Development Associates' $4.3 million test facility at Detroit Edison's Delray generating station is well under way, the APDA executive committee announced. The facility will permit testing both for safety and design, under operating conditions but without the use of actual nuclear fuel, of full-size components of the fast-neutron breeder reactor being designed by APDA. Components now under procurement include the reactor vessel; the rotating shield plug assembly above the reactor core; the offset handling mechanism mounted on and extending through the shield plug and used to insert and remove fuel and blanket elements and control rods; and a vertical sump-type centrifugal liquid-sodium pump with a 11,800 gpm capacity. General Electric, Combustion Engineering, Borg Warner, Commonwealth Associates, United Engineers and Constructors, and Babcock & Wilcox are among the firms under contract to APDA for components. The test facility is expected to be in operation early in 1957.

Britain names first 2 A-power sites. The Central Electricity Authority has selected Bradwell in Essex and Berkeley in Gloucestershire as locations for its first two 2-reactor power stations under the ten-year White Paper program. Bradwell, 6 miles northeast of Southminster at the mouth of the Blackwater River, has a population of about 800; Berkeley, on the Severn estuary 24 miles north of Bristol, is a market town of the same size. Plant sites in both cases will be away from built-up areas; they are subject to review by local planning authorities and the Minister of Fuel and Power. Construction is to begin in 1957. Six more sites have been provisionally selected.

LMFR economically attractive, B&W reports. An exhaustive study of BNL's liquid metal fueled reactor carried out by 17 organizations under the supervision of Babcock & Wilcox reported to the AEC that the system is "technically feasible in the near future," and "gives promise of being economically attractive." A 226-Mw reactor fueled by a liquid U-Bi alloy could be built and operated at a cost of 7.1 mills/kwh, B&W said; and for four reactors totaling 905 Mw built on one site, the cost would drop to 6.5 mills. The system can be made regenerative with a breeding factor as high as 0.8.

Danes choose reactor site. The Danish Atomic Energy Commission decided to locate the first Danish Atomic Research Center on the Risø peninsula. The site, 20 miles west of Copenhagen, is the closest to the capital of four sites considered. But the Danish AEC had sought a location not too far removed from Copenhagen, feeling the Research Center should be easily accessible to scientists and students, and close to a power plant.

World News.

Activity in Near East. Syria and Iraq, neither of which have as yet concluded bilaterals with the U. S., both are now hoping to get a research reactor at half-price under the plan President Eisenhower announced this summer.

Syria's ministry of health is studying the plan with a view to improving the country's agricultural produce and to eliminating several contagious diseases. Officials in Baghdad said Iraq would welcome any U. S. atomic aid in education and industry as well as agriculture and medicine.

Meanwhile Maj. Muheddin Mekhouli of the Egyptian Atomic Commission visited Lebanese Premier Rashied Karami and concluded an agreement for cooperation and exchange of information between the two countries in the atomic field. A U. S. research bilateral has been signed with Lebanon but not with Egypt.

Ceylon to press for U. S. reactor. The government decided to make a full-scale bid to obtain for Ceylon the reactor-equipped nuclear research center offered to the Colombo Plan countries of southeast Asia by the U. S. Ceylon's diplomatic envoys in Colombo Plan countries will canvass support for Ceylon's claim. The U. S., which will contribute $10- to $15-million for the center, insists it be equally available to all Colombo Plan nations.

Radiation protection course starts. The first international course in protection against radioactivity, lasting five weeks, began in Stockholm last month. Taking it are 21 health physicists from Belgium, Denmark, France, Iceland, Italy, Netherlands, Norway, Sweden, Switzerland and West Germany. The course director is Dr. Elda E. Anderson, chief of the training section for radiation protection at ORNL, lent by the AEC; other lecturers came from Britain and France. The course is intended particularly for health physicists in European countries where atomic energy programs are now in a rapid, if comparatively early, stage of development. It is a direct outgrowth of the Geneva conference in August, and is sponsored jointly by the World Health Organization and the Swedish government. Acting as hosts are the Swedish Atomic Energy Corp., the Royal Board of Medicine, and the Radiophysics Institute of the Karolinska Hospital.

Mexico prepares for A-power. Mexican Light & Power Co., owned largely by U. S., British and Belgian capital, has embarked on a broad educational program. Since July it has been conducting classes in nuclear energy for 100 of its engineers; it has established 5 scholarships for a year's work at Michigan Univ., of which 2 are to go to its own engineers and 3 to students of Mexico City colleges; and it has been telling the Mexican public about the benefits of atomic energy applied to the generation of electricity through full-page newspaper ads and through leaflets distributed with monthly bills. However William H. Draper, Jr., board chairman of Mexlite, said his company has as yet no "publicly-announced" plans to purchase a reactor.

There has been some speculation that one of the 3 reactors American & Foreign Power announced it would install in Latin America would go to Mexico, although the company says it has not yet decided which countries would be chosen. An A. F. & P. subsidiary, Cía. Impulsora de Empresas Eléctricas, is the only other major foreign power company operating in Mexico besides Mexlite.

Giant British accelerator planned. Metropolitan Vickers is designing and manufacturing a 50-Mev proton linear accelerator, in collaboration with the U. K. Atomic Energy Authority, for Harwell. This will be the pilot section for a projected 600-Mev accelerator, will aid design studies for the larger instruments. Biggest atom-smasher in Europe today is a 400-Mev synchrocyclotron at Liverpool.

Joint Scandinavian research center planned. The Nordic Council at its January meeting in Stockholm will explore further the possibility of establishing a Nordic institute for atomic research. Representatives of Denmark, Iceland, Norway and Sweden discussed the question earlier this fall; it is hoped Finland also will participate. The institute would be located in Copenhagen to maintain closest ties with Niels Bohr's famous Institute of Theoretical Physics. Denmark would defray building costs, and Sweden and Norway would contribute toward operating expenses; Sweden also has uranium supplies and Norway heavy water.

In addition Swedish industrialists Axel Wenner-Gren has offered to pay the greater part of the cost of establishing an inter-Scandinavian atomic research institute to be located in Stockholm and named the Wenner-Gren Center.

Atomic training in Germany gets impetus. West German Minister for Atomic Questions Strauss announced a government program for establishment of chairs and courses in nuclear science. One week later the Technische Hochschule in Aachen announced it was starting at once to train nuclear engineers. "Aachen is primarily interested in atomic power station engineering, as is natural for a university situated close to the lignite fields which contribute an important part of the electric power supply of this part of Europe," said Dr. Wilhelm Fuchs, director of the university's physics institute. He saw no great difficulty in starting to train young engineers, he said: the essential theoretical studies were available, and the Aachen faculty had already sufficient practical acquaintance with the working of atomic plants abroad to start teaching. The U. S. and U. K. were already establishing themselves in the atomic power export business, he said, adding he saw no reason why Germany should not enter it also.

Reactor Plans in Sweden. Sweden officially announced plans to build two atomic power stations, at a total cost of $40 million. One will be a 75,000-kw heating plant, to be ready in 1960; the second, a 100,000-kw plant for generating electricity, is for 1962 completion. Both are joint projects of the Board of Waterfalls (the Swedish power administration), the Atomic Energy Corporation and the Asea Electric Co. The first will be built near the Asea factories at Västerås in Central Sweden 60 miles from Stockholm; the second will be underground in the mountains of southern Sweden. No choice of reactor type has been made yet, according to Swedish power chief Ake Rusck, but "indications are that we will use natural uranium with heavy water as moderator." Equipment is expected to come largely from Swedish suppliers.

ROUNDUP

News in Brief

New reporting requirement to be set by AEC. One new regulation not yet out but due shortly is that covering the Sec. 57a(3) general authorization granted in October for American companies to talk to foreign countries about unclassified atomic activities. The new regulations will include a requirement for reporting to AEC, but only on actions taken—not on preliminary contacts or negotiations. AEC wants to know what kind of equipment is sold, and to whom.

Bids asked for Latin American reactors. Ebasco Services invited 16 companies to submit proposals on one, two or all three of the power reactors American & Foreign Power will install in three Latin American countries. Ebasco is acting agent for A&FP in procuring, designing and constructing the plants. Proposals are due Jan. 16. The three countries have not yet been selected, but are likely to be among the 11 in which A&FP now has operations.

Reactor materials course set. The Atomic Industrial Forum, sponsoring a course for the first time, has arranged a two-week session Jan. 30 to Feb. 10 on reactor materials at Northwestern U., Evanston, Ill. The concentrated course is designed for senior chemists, engineers and metallurgists; L-clearance is required. Tuition is $100. Deadline for applying is Dec. 15.

Wheat swapped for thorium. The U. S. atomic energy program drew a side benefit from attempts to solve the long-tangled agricultural surplus problem. In a sweeping $41-million deal with Brazil for unloading surplus U. S. wheat, $2.8-million is earmarked for buying Brazilian thorium and other rare earths for stock-piling in this country.

First private linear accelerator sold. High Voltage Engineering Corp. sold the first linear accelerator to go to private industry. The $165,000, 6-Mev, 4-kw machine now being built for an unnamed drug firm will probably be used for pharmaceutical sterilization. Meanwhile High Voltage announced plans to quadruple existing facilities and move to a new 45-acre site at Burlington, Mass.

Chicago University honors Fermi. The Institute for Nuclear Studies of the University of Chicago was officially renamed the Enrico Fermi Institute of Nuclear Studies.

Carbide Oak Ridge contract prolonged. The AEC's contract with Union Carbide & Carbon Corp., which still had a year and a half to run, was extended three more years until June 30, 1960. UCC, through its newly-formed subsidiary Union Carbide Nuclear Co., operates ORNL, the Y-12 plant at Oak Ridge, and the gaseous diffusion facilities at Oak Ridge and Paducah, Ky., for the Commission.

Papers solicited on nuclear medicine, scintillation counters. The fifth Scintillation Counter Symposium has been scheduled for Washington (Shoreham Hotel) on February 28–29, and contributors of papers are asked to submit them by December 15 to Dr. J. B. H. Kuper at BNL, Upton, N. Y. Also asking for papers is the Society of Nuclear Medicine, for its 1956 annual meeting to be held June 21–23 in Salt Lake City. Outlines should be sent Dr. Simeon Cantril at Swedish Hospital, Seattle, Ore., by January 1.

Regional nuclear medicine group formed in Chicago. The Central Society of Nuclear Medicine has been organized by physicians and other professional workers in the Midwest who wish to promote interest and investigation in nuclear medicine. Those interested may contact Robert S. Landauer, Radiation Center Building, 1903 W. Harrison St., Chicago 12, Ill.

New step in international cooperation. The first commercial meetings with another nation for discussion of classified atomic energy information for civilian uses were held by Nuclear Metals, Inc. of Cambridge, Mass., and Atomic Energy of Canada, Ltd. Talks were on types of fuel elements to be used in Canada's power demonstration reactor program under the terms of the U. S.-Canadian power bilateral. Permission to hold the talks was granted by the AEC.

New fellowships established. The AEC will offer more than 75 awards for study in industrial hygiene and in radiological physics during the academic year 1956–57. Up to 25 health physics fellowships each will be available at Rochester U. in cooperation with BNL; at the University of Washington with Hanford; and at Vanderbilt U. with ORNL. Industrial hygiene fellows attend either Harvard or Pitt. The stipened is $1600.

GE stakes out California claim. Alameda County, 6 miles from Livermore and 40 east of San Francisco is the site of a 1,585-acre tract on which GE took options as a possible location for a future nuclear development facility. Exact use of the land will depend on GE's requirements, zoning and other problems. The development facility's long-term purpose will be the application of atomic energy to a wide range of peaceful uses; one immediate such task is support work on GE's 180,000-kw dual-cycle boiling reactor for Commonwealth Edison of Chicago. Temporary HQ for the dual-cycle project staff is at San Jose, Calif.

Public power group complains on AEC fuel policy. The American Public Power Assn. charges that AEC fuel lending policies have the effect of setting up "a new government lending program" favoring private industry. The Commission charges 4% a year on the total value of enriched U loaned to reactor operators. The APPA argument is that if the law permitted sale of fuel and utilities had to buy it, private operators would have to pay from 5.6% to 6.9% interest to finance purchase, while public utilities can borrow money for less than 4%. This amounts to a "1.5% to 2% penalty for public utilities," APPA says.

NYU offers radiation safety course. In cooperation with the AEC, NYU's Institute of Industrial Medicine is giving an introductory course in radiological safety, followed by lab sessions. The course will be given full-time beginning Jan. 9, and part-time beginning Feb. 2.

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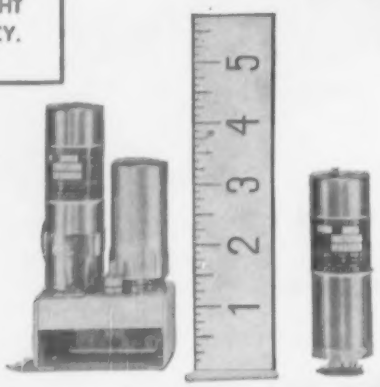

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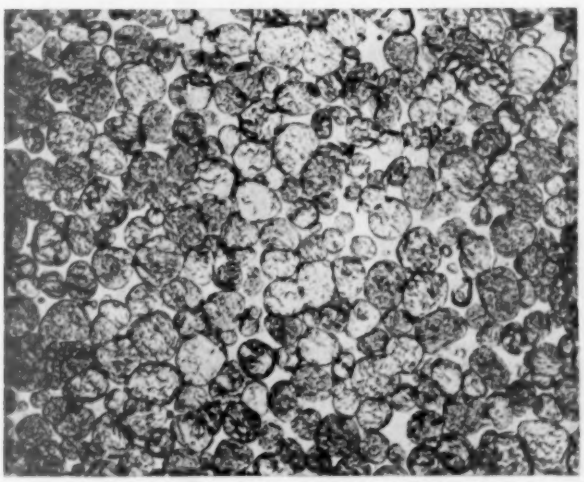
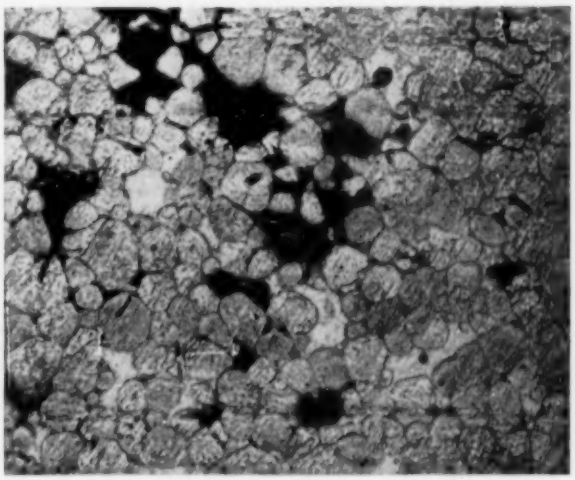


Mallory 1000 Metal, under high magnification, shows completely uniform grain structure. Its high density extends through every part of the piece . . . free from voids and weak spots.



Voids in less uniform metals look like this under the microscope. They seriously impair shielding effectiveness and tend to make performance unpredictable.

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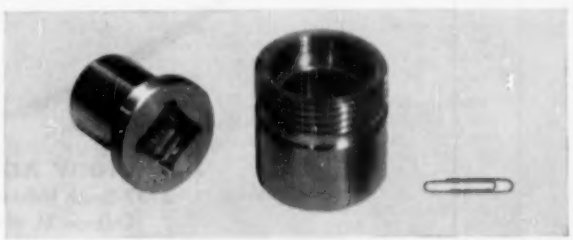

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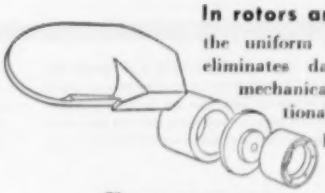

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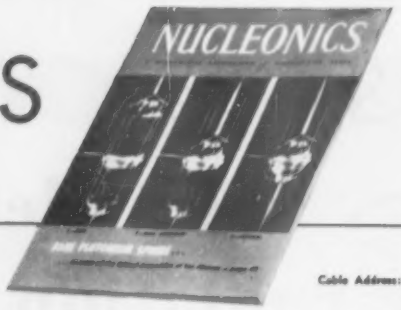

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Radiation Instrument Development Laboratory

2237 WEST 67th STREET CHICAGO 36, ILLINOIS

October 7, 1955

Nucleonics Magazine
McGraw-Hill Publications
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Attention: Bruce Winner

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The above advertisement is a reproduction of the one which appeared in NUCLEONICS. 52 inquiries resulted with total sales of 14 units amounting to $191,100.00 plus accessories.

NUCLEONICS . . . the magazine most in demand by GE's Hanford scientists and technicians

The magazine most in demand by people employed at the General Electric Hanford Atomic Plant is NUCLEONICS with 217 plant subscribers. This information was recently reported to us by C. G. Stevenson, head of the Technical Information Unit.

This news release is just another example of the view taken by influential people in the nuclear energy industry as their proof that NUCLEONICS is used by these men as their prime source of information.

In this and in other reader-and-user inspired releases, the praise is the same: NUCLEONICS serves a vital function of being *useful* to an industry! From the "Nucleonics Reader Survey" conducted amongst readers of the magazine comes a multitude of write-in sentiments, unsolicited by the publication. Some of these were:

"The copy of NUCLEONICS sent to me is equivalent to a library copy as it is circulated to more than a dozen persons in our division. Their combined interest would include almost every phase of atomic energy. . . ."

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and

"I read NUCLEONICS because it is the publication most likely to help me in my work. The information I seek is any that pertains to my type of work."

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These examples could actually be multiplied a hundredfold. These are extracts and may be had in full by writing to NUCLEONICS and requesting the "Nucleonics Reader Survey." It is free for your asking. If you, like RADIATION INSTRUMENT LABORATORY (advertisement shown at the left, as it appeared in the August 1955 issue of NUCLEONICS) have products which have applications in the *growing* nuclear energy field, be sure to call or write to your nearest NUCLEONICS representative or to the address at the bottom of this page.

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COMPACT CONSTRUCTION consists of a zinc-sulphide phosphor, photomultiplier tube and cathode follower pre-amplifier giving 0.25 volt output pulses. These pulses are transmitted to a scaler or rate meter. The detector also makes a rapid and sensitive survey meter when connected with a simple audio-speaker, which produces an audio "popping" noise.

PRICE is $249.60* and the detector is available from stock. For further information contact nearest G-E Apparatus Sales Office, or write for Bulletin GEA-6117, Section 605-81, General Electric, Schenectady 5, N.Y.

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NUCLEONICS DECEMBER, 1955

Jerome D. Luntz, *Editor*

From Perhapsatron to Columbus

[EDITOR'S NOTE—*With detailed technical information on controlled thermonuclear power still kept classified, those outside AEC's Project Sherwood have had to rely on rumor and strained interpretation of cautious official releases for their information. As part of a continuing policy of promoting the broadest possible release of information on this subject,* NUCLEONICS *elicited the following amplified official statement of thermonuclear-power research under way at Los Alamos.*]

As Admiral Strauss has announced, the existence of large quantities of energy locked up in the atoms of the light elements has been well known to physicists for many years, and many of them have speculated on the possibility of releasing it in a useful way. Several classified articles, and even proposals for machines, based on controlled thermonuclear reactions, were prepared at Los Alamos as long ago as 1946, though these matters were regarded more in the nature of interesting speculations and quite secondary to the urgent military requirements of that period. However, fairly extensive experiments on colliding jets were made in 1946–47, under the direction of J. Willig, based on a theoretical paper by J. L. Tuck and S. M. Ulam on thermonuclear effects from colliding jets from shaped charges. This is perhaps noteworthy only since it happens to be the method put forward by Homi J. Bhabha at the Geneva Conference.

In 1951, fresh upswelling of interest in the subject of controlled thermonuclear reactions occurred independently at Los Alamos and at Princeton, the former being attributable to James L. Tuck and the latter to Lyman Spitzer.

The first experimental program got underway at Los Alamos in January, 1952, followed by Princeton in mid-1952, using a different method, and Livermore under Richard Post by a third method somewhat later. The general subject of controlled release of thermonuclear energy rose with rapidity to the status of a major AEC project known as Project Sherwood.

At Los Alamos, the first apparatus, appropriately called the Perhapsatron, was built to conduct fundamental studies on the self-contracted discharge or Pinch Effect and engaged the following: W. A. Arnold, L. C. Burkhardt, J. A. Phillips, G. A. Sawyer, E. Stovall, O. Swickard, and J. L. Tuck. Some of the results of this work are now declassified and will soon appear in the literature, and earlier measurements by some members of this group on the DD, TD, and He^3D cross sections have been published for some time.

Since that time, there have been expansions in several directions, and although we still have Perphapsatrons at Los Alamos, we now have Columbus (a distinctly forward-looking name), and contemplate devices with such names as Picket Fence.

By now, too many individuals are involved to give names in detail, but, in summary, there exist experimental groups K-3 with J. A. Phillips as Group Leader, the recently added K-4, V. Josephson, Group Leader, and an extensive theoretical contingent including J. Holladay, R. Landshoff, C. Longmire, M. Rosenbluth, J. Suydam, with considerable assistance from the electronic computing machines. J. L. Tuck is in technical charge and member of the AEC Sherwood Project Steering Committee.

The Los Alamos branch of the Sherwood Project has been very fortunate in capturing the interest of many brilliant scientists from universities in all parts of the country, and the following are some of those who worked on this project on a consultant basis during the summer of 1955: Professors W. P. Allis (MIT), W. Bennett (NRL), K. Brueckner (Brookhaven National Laboratory), S. Chandrasekhar (Yerkes Observatory), G. Chew, Donald Kerst, Francis Low (U. of Illinois), Marvin Goldberger (U. of Chicago), and Kenneth Watson (U. of Wisconsin).

As for technical information, it is not possible to add much to what has been said before. The following two points might be mentioned: First, the long-term nature of the project must be emphasized. Second, since hydrogen bombs exist, the study of the controlled release of thermonuclear energy might be associated in the public mind with such hazards as tremendous explosions, that can be restrained only with difficulty. No such hazards have been encountered yet. The main problem seems likely to be that of getting enough thermonuclear energy back from the material heated to 100 million degrees, to repay the power used to achieve and maintain this high temperature.

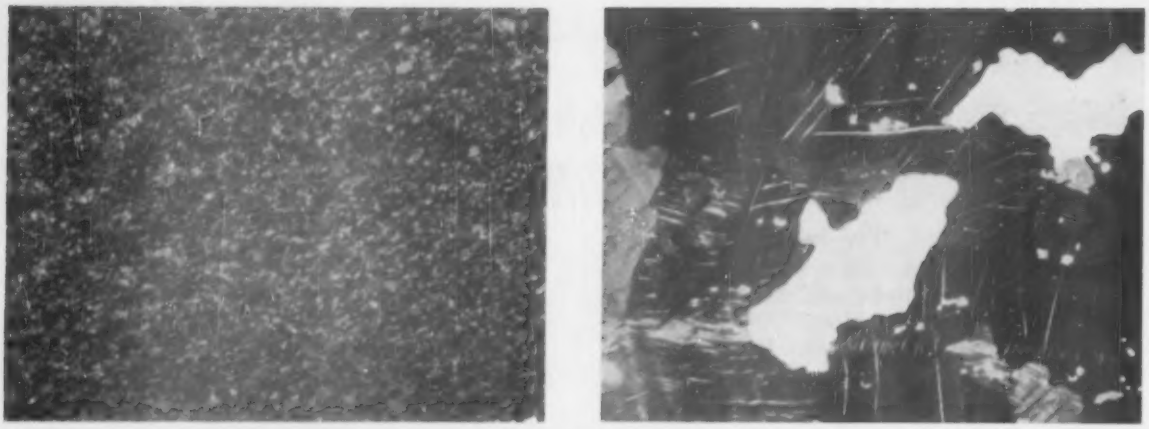

FIG. 1. Fine grained, random orientation in U made by powder metallurgy is evident (left). Comparison is beta-rolled U (right), usually thought of as fine grained. Polarized light used to take photographs. Magnification for both photos is 200 ×. (Photos courtesy of Sylvania Electric Products, Inc.)

Powder Metallurgy Makes Better Reactor Fuels and Components

Techniques and advantages of powder metallurgy for reactor uses are presented in this summary. Better resistance to radiation and applicability to unusual combinations are two main reasons for high interest in these methods

WHY IS POWDER METALLURGY so interesting to reactor engineers? It seems that powder-metallurgy products are less susceptible to radiation and show less radiation damage when used in reactors. The fuel elements of several reactors under design cannot be made any other way. I refer especially to fuels made of metals and nonmetals (cermet-type materials). Going further, in my opinion, powder metallurgy will be able to solve many problems of reactor design."

With words like these, H. H. Hausner, of Sylvania Electric Products, opened a symposium on powder metallurgy in atomic energy, jointly sponsored by the Atomic Energy Commission and the American Society for Metals. In this article, NUCLEONICS summarizes some papers presented at that meeting, held Oct. 20, in Philadelphia.

Metallurgical Problems

The general problems of materials for reactors may be classified using four factors, said V. P. Calkins, General Electric Co., Aircraft Nuclear Propulsion Dept.

Physical and mechanical properties. The complicating factor in a reactor's mechanical demands is internal heat generation. Heat liberated inside a fuel must be able to pass to the coolant or the system will simply melt and vaporize, for heat produced by fission is nearly independent of fuel temperature. Fuel-matrix materials must have a very high thermal conductivity, and a sound metallurgical bond is needed between fuel and cladding. Even in this case, there is a large thermal stress because of the center-to-surface temperature gradient.

Nuclear property requirements. Materials used in the reactor must have low cross section. These include the fuel matrix, moderator, core structure, reflector and coolant, and associated piping and structures. For control, materials must have high cross section. For components usually in a high radiation field, but that are frequently removed, materials with low absorption cross section are desired. Induced radioactivity is thereby minimized.

Corrosion. In two ways corrosion is more important in reactor systems than in others. One, if the fuel cladding fails, highly radioactive fission fragments will contaminate the coolant stream, causing much trouble. Two, temperature along a fuel-element cladding may vary considerably because of uneven heat transfer across the bond. These temperature gradients could accelerate corrosion.

Radiation damage. Both metallic and nonmetallic materials are subject

to adverse changes in physical and chemical properties as a result of radiation exposure. Metals are over a thousandfold less susceptible than organics, in general (*1, 2*). Damage is caused by fission fragments or fast neutrons dislocating atoms within the atomic lattice. Figure 1 shows a grain-size comparison.

Powder-metallurgy advantages. In many cases powder metallurgy is the only way we know of to make materials in the desired forms. It allows making sound bodies even though the constituents may be highly reactive in the liquid state. Segregation during solidification is eliminated. Beryllium oxide or carbon can be pressed and a good, sound, moderator body made. Boron or its compounds can be made part of metal matrices. Boron could be considered more nonmetallic than metallic; it does not form structural alloys.

New Methods

Fuel elements need a controlled, fairly uniform distribution of fuel within the core, dimensional stability and radiation resistance, said J. H. Coobs and W. D. Manly, Oak Ridge National Laboratory. A mixture of a refractory fuel compound and a matrix metal has these advantages: matrix metal may be the same as cladding, to minimize compatibility problems; by using a fuel that is compatible with the matrix and cladding metal, diffusion of fuel is eliminated; fuel distribution and concentration can be closely controlled; and the methods and related techniques are adaptable for other components.

Some new highly adaptable powder-metallurgy techniques are available for fabricating the various reactor parts. The table (p. 26) summarizes applicability of the new methods for these parts.

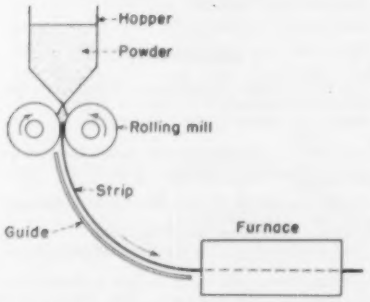

FIG. 2. Powder rolling is a new technique that possibly will be used for fuel-element fabrication. Control rods and neutron shields are more likely to be made this way

Powder rolling. In powder rolling (Fig. 2) horizontal rolls are fed 50-mesh powder from hoppers just above them. Final thicknesses of 10–14 mils are made from $2\frac{3}{4}$-in.-diameter rolls. The green strip is sintered in a furnace. Repressing of the sintered strip two or three times produces sheet with excellent properties. Clad strip can be made (*3, 4*).

Electrophoresis. In electrophoresis, small nonconducting particles are deposited on metals by high-voltage acceleration of colloidal particles suspended in acetone, alcohol, or other high-dielectric solvent. F. Fahnoe and J. J. Shyoe of the Vitro Corp. have applied this method to many metal oxides. Deposited layers are uniform and can be precise in thickness. Only a few mils can be deposited in a reasonable time. Simulated infiltration of porous materials has been developed.

Extrusion. The powder mixture is precompacted into a billet, and usually canned before extrusion. The billet can be made by pressing and sintering, hot pressing, or hot compacting in the blanked-off extrusion chamber. Extrusion has been successfully used for experimental powder-base fuel elements. The can is bonded during extrusion to serve as the cladding. Using a three-ply composite billet, seamless tubing with protective cladding both inside and out might be made.

Cold pressing and sintering. This standard method has been used quite successfully in conjunction with other processes, such as repressing, and hot pressing. It is the only method useful for some cermets. Fuel elements for the Geneva conference reactor were made this way (*5*).

Hot pressing. For hot pressing below ~600° C, metal dies may be used, with pressures ~10 ton/in^2. Graphite dies can be used to 2,200–2,500° C, at 2,500–3,000 lb/in^2 in a furnace such as shown in Fig. 3. The method is inherently expensive, but can be justified where excellent properties are needed.

Infiltration. In infiltration a porous skeleton of refractory-base material is treated with molten metal. The metal must wet the skeleton completely.

Hot coining. Hot coining consists of stamping the hot sintered compact directly from the sintering furnace. The technique is most useful for cermets.

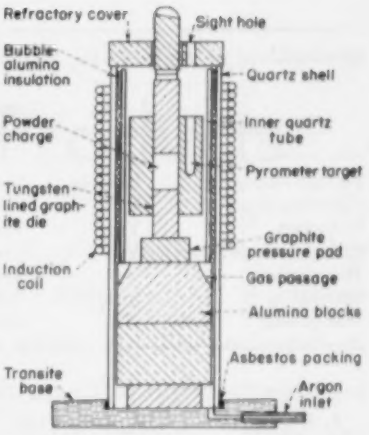

FIG. 3. Furnace used for hot pressing at temperatures up to 2,500° C. Pressures of 3,000 lb/in^2 can be used

Preparing U Powder

One way of making U powder is to form the hydride, UH_3, said P. Chiotti and H. A. Wilhelm, of Iowa State College, and decompose it. Optimum temperature for forming UH_3 is 225° C. Reaction rate is much lower below 200° C or above 250° C. Trace impurities in H_2, or an oxide film on U result in an induction period with slow reaction time.

At 250° C 100 gm of clean shavings is converted in 30 min., a single 100-gm piece of metal takes $1\frac{1}{2}$–2 hr (*6*). Product is a finely divided and highly pyrophoric powder.

Hydride decomposition. By heating under reduced pressure the hydride is readily decomposed. At 300–400° C, a slightly sintered metal powder results. This can be broken up to give a 3–10 micron averaged-sized particle.

Preparing Th Powder

Problems involved in preparing Th are similar to those for U. Tonnage-scale operations have been operated using Ca reduction of ThF_4 (*7*). The ThF_4 is made by precipitation of thorium oxalate from purified thorium nitrate solution, followed by calcination to the oxide, then hydrofluorination of the oxide.

In the Ca reduction, the metal is first obtained as a massive Th-Zn alloy because the charge contains anhydrous zinc chloride, to help separate the Th. Zinc is distilled off in vacuum, leaving Th-metal sponge.

Procedure for making Th powder consists of these steps (*8, 9*):

Applicability of Methods for Fabricating Reactor Components

Method	*Fuel elements*	*Control rods, neutron shields*	*Gamma shields*	*Moderator materials*	*Accessories*
Powder rolling	Possible	Yes	Possible	No	No
Electrophoresis	Yes	Yes	No	No	No
Extrusion	Yes	Yes	No	No	No
Cold press and sinter	Yes	Yes	Yes	No	Possible
Hot pressing	Yes	Yes	Yes	Yes	Yes
Infiltration	Yes	Possible	Yes	No	No
Hot coining	No	Yes	Possible	Possible	Possible

1. Formation of the dihydride, ThH_2, at 600–650° C at 1-atmosphere H_2 pressure. During this step the charge swells, but does not break up into a powder.

2. Formation of the higher hydride, Th_4H_{15}, at temperatures not above 320° C. Best temperature for this step is 250° C. The charge scales and breaks into a coarse powder.

3. Decomposition of the higher hydride by heating to 500° C at 1-atmosphere H_2 pressure.

4. Decomposition of the lower hydride at 700° C at low pressure. At this temperature, the dissociation pressure of $ThH_{0.025}$ is about 1.0-mm Hg. Resulting Th powder is coarse, but can be easily broken up to pass a 30-mesh screen.

Equipment. For small lots, a fused silica tube can be used. For 10 lb or more, a steel (preferably stainless steel) reaction chamber is used. A charge of lathe turnings or chips is preferable. Conversion time for 10 lb of these is 8–12 hr.

Powder Metallurgy of U

U powder made by the hydride method is a fine powder, the particles of which are usually agglomerations of still finer particles, according to H. H. Hausner, Sylvania Electric Products. The powder does not compact very well at room temperature. Even using 50 tons/in² pressure, the "green" density is 12.5 gm/cm³ or 66% of theoretical density. Compacting at higher pressure results in better densities, but these high pressures are hardly feasible for large-scale production.

Sintering these compacts in vacuum at 1095° C (3% below melting temperature), and even sintering just below melting temperature, does not result in any complete densification. Comparing densification during sintering shows that zirconium- and thorium-metal powders sinter very readily, that beryllium sinters poorly, and that U powder is the poorest. This does not mean that powder-metallurgical processes are not applicable to U.

Density and grain-size variables. Density results of the various processes applied to U powder are:

1. Compacting U powder, even at 100 tons/in² results in low density.

2. Sintering close to the melting point still results in low density.

3. Repressing at very high pressures, up to 175 tons/in², does not considerably increase the density.

4. Hot pressing of U powder at 600° C results in complete densification. This is a desirable fabrication means.

Grain size of the U is as follows:

1. U sintered after compacting at temperatures in the gamma range (> 764° C) yields very coarse grains.

2. Repressing and annealing the sintered U causes a fine grain structure to form within the coarse grains. The fine sub-grains are oriented in the same direction as the coarse grains.

3. Hot pressing U powder in the alpha temperature range (< 663° C) results in a true fine grain structure.

Powder Metallurgy of Th

Experience with two different Th powders was reported at the Geneva conference (*10*). H. H. Hausner summarized the report by G. A. Meerson of the USSR. One powder was made by Ca reduction of ThO_2, the other by electrolysis. Apparent density (2.6–3 gm/cm³) was lower for the Ca powder than for the electrolytic one (4.5). Both powders compact without difficulty, but 1.5–2 times as much pressure is needed for the Ca powder, to get the same density.

Compacts made from both powders were sintered in 0.005-mm Hg vacuum and effects of temperature and time on mechanical properties were studied. For electrolytic powder, 1,100° C is optimum. Sintering at 1,150–1,200° C caused cracks and blisters in Ca powders. The Ca impurity probably causes these cracks.

Repressing at 10–14 tons/cm² and annealing at 1,100° C increases density, strength and ductility. For the electrolytic Th, final density is 11.62, strength is 16.6 kg/mm², yield strength is 8.0 kg/mm², elongation is 35.0% and hardness is 53 kg/mm². For Ca powder, these constants are (in the same order) 11.51, 21.7 kg/mm², 13.5 kg/mm², 20.0%, and 70 kg/mm².

Th powder made from hydride. Experimental work with Th powder made by decomposing the hydride has been described (*11*). Compacting the powder at 50 ton/in² results in high density. The material can be completely densified by sintering at 1,300° C.

U-Al Alloy Formation

In alloys > 20% by weight U, powder metallurgy is used to keep the compound particles small, said H. A. Saller and F. A. Rough, of Battelle Memorial Institute. Alloys containing 42 wt. % U were made using atomized Al and powdered compounds. Both UAl_4 and UAl_2 were used. These were made by melting the mixture, and then crushing the compound. Two ranges of particle sizes, minus 150 plus 20, and minus 325 mesh were used.

To make alloys, the compound powder was mixed with minus 325-mesh Al. Cold pressing at 50 ton/in² made compacts. These were sintered at 450–600° C for 4–96 hr. Particle sizes remained unchanged.

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First Step in Ultimate Waste Disposal:

Concentrating Fission Products

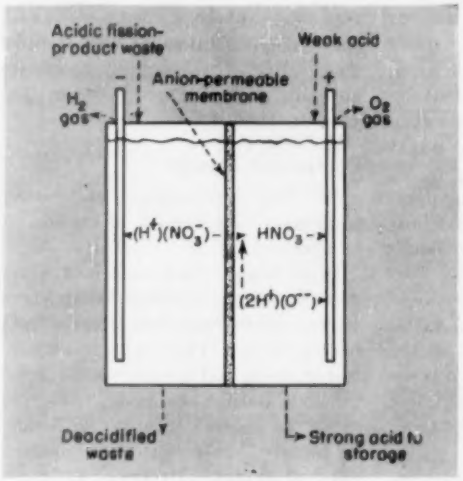

FIG. 1. Deionization cell uses anion-permeable membrane to produce deacidified waste

500-Mw reactor produces about a pound/day of fission products. Only part of these are long lived. Separating the fission products from bulk wastes is an essential pretreatment before attempting final fixation. Here are ways of doing this for wastes from unalloyed, and Al- and Zr-alloyed fuels

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METHODS OF SEPARATING nonactive salts and concentrating bulk waste volumes, before treating the wastes for permanent disposal, are presented in this article. Processes for handling wastes from natural or slightly enriched U fuel elements, U-Al-alloy fuel elements, and U-Zr fuel elements, and preliminary equipment designs are given. First we will consider the need for such treatment.

Why Remove Nonactives?

High-level atomic wastes, as we know them today, contain the hazardous fission products in very small amounts, compared with the amount of inert salts in the aqueous waste solutions. In ultimate disposal, we must be concerned with the chemical and physical behavior of longer-lived fission products, for example Cs^{137} and Sr^{90}, over several centuries. Fixation of the hazardous substances in stable solids, as a means of permanent disposal, therefore becomes a logical objective. Thus, we must look for methods of treating the raw wastes strictly in accordance with this principle and not become primarily involved in methods of processing the wastes as bulk solutions. This objective will best be realized if the fission products are first separated from the extraneous salts for subsequent fixation (*1*), or if the salts themselves are transformed into stable solids that serve as permanent repositories for the fission products.

Ultimate Disposal

In the present scheme, adsorption and fixation of fission products on montmorillonite clay are basic; advantages are (*2*); (*a*) adsorbed ions can be fixed by heating the clay to 1,000° C; (*b*) the clay has good capacity for fission products—1.2 milliequivalents/gm; (*c*) the clay is highly stable before and after heating; and (*d*) the clay is widely available, and relatively inexpensive.

Experiments on the clay over the past 6 years have demonstrated its capacity for adsorption and fixation of fission products (except ruthemium). In the authors' opinion, the only serious problems remaining relate to pretreatment of the bulk wastes to eliminate extraneous-ion interference. Separating nitric acid, aluminum nitrate, and zirconium and aluminum fluorides are specific examples.

Removing Nitric Acid

Wastes from processing unalloyed U fuels usually have HNO_3 as the main constituent.

Distillation. An adequately demonstrated method of deacidifying these wastes is by distillation. At least 90% of the acid may be removed and recovered for further use. While this is a large improvement, it is desirable to carry acid removal even further, to obtain maximum clay effectiveness.

Deionization cells. Further HNO_3 removal may be obtained using an electrodeionization cell with ion-selective membranes (*3*). These membranes pass ions of one charge while remaining impermeable to ions of opposite charge. An anion-permeable membrane is used for HNO_3 removal. Such a cell is shown in Fig. 1. It is not practical to remove all the acid in this unit, because at very low concentrations the cell resistance becomes high. But acid removal to 0.05*N* has been found feasible. This means an over-all reduction in acid concentration of 1,000, considering also the distillation step. Laboratory tests on the membrane cell have been very promising, and a pilot-scale unit is being developed.

Removing Al Nitrate

Dissolving U-Al-alloy fuel elements in HNO_3 gives a waste high in $Al(NO_3)_3$.

Al concentration in this waste is 10^4 times greater than fission-product concentration. Because Al is a trivalent cation, it is strongly adsorbed by the clay. It must be separated from the fission products before clay adsorption.

Deionization cell. The $Al(NO_3)_3$ can be converted to the insoluble hydroxide with an electrodeionization cell, and then to the oxide without the substitution of other ions. Unlike the gelatinous $Al(OH)_3$ formed by chemical treatment, the cell product is somewhat crystalline and is easily removed by filtration. Drying the products and heating to 300° C, followed by leaching with water or mild acid separates the fission products from Al. Separation is not complete for any of the fission products, although cesium and Sr separate better than the others. Aluminum oxide stability is of first importance, because it would always contain some fission products.

Although development is continuing on the membrane systems, a more direct method of converting $Al(NO_3)_3$ to the oxide was found.

Thermal decomposition. The process developed consists of first evaporating the waste to dryness, then converting the residue to the stable oxide by heating to high temperature. The oxide is then leached with water or acid to remove soluble fission products. Fission products that cannot be leached away in this manner can be considered permanently fixed in the aluminum oxide, and the oxide can then be disposed of without further treatment.

Results of an extensive series of experiments to determine leaching of fission products are summarized in Table 1. With temperatures above 600° C, cesium is the only fission product removed to any great extent by distilled-water leaching. Radiocesium pure enough to use as a source might be recovered by this technique.

Further removal of fission products may be obtained by leaching with acid, if necessary. Leach liquor could then be deacidified before contacting it with the clay.

Vitrifying or glazing agents, to facilitate fission-product fixation in the aluminum oxide, are being investigated. Also under study is the effect of firing at temperatures up to 1,400° C.

Removing Zr Fluorides

Considerable interest is being shown in Zr-alloyed fuels for power reactors. Much waste from these fuels may be produced in the future. The main constituents are Zr and Al fluorides, at present. As with the Al-alloy wastes, converting to stable Zr and Al oxides is a method of separating the fission products. This procedure gives an end product that is highly stable in nature, and can be safely disposed of.

Although the fluorides do not decompose to the oxides by heating, they may be converted to the oxides by hydrolysis with steam at high temperature. Good conversion is obtained at temperatures above 700° C. Leaching tests are now underway. Partial results are given in Table 2.

Equipment Design

In the development of process equipment, continuous operation is emphasized.

Drum dryer. One unit is a drum dryer converter, in which the $Al(NO_3)_3$ waste is fed to the surface of a revolving heated drum. The waste is concentrated, dried, and the residue converted to oxide during one revolution. Because the product is insoluble, it may be removed under water to minimize the dust hazard. Vapors given off are almost completely condensable.

Two possible disadvantages are: (*a*) low heat transfer rate; and (*b*) the drum presumably must be cooled during each revolution ahead of the point where liquid feed is added.

Combined ball mill-kiln. A more promising design, combining a ball mill and rotary kiln, has been developed that eliminates the drum-dryer disadvantages and permits a much wider range of temperatures to be used. The unit used in the first tests is shown on the cover. Design of a more complete unit is given in Fig. 2.

Liquid waste is fed into the first ball-mill section where water is evaporated and the dried $Al(NO_3)_3$ is converted to free flowing granules. The granules then separate from the balls and are transported by rotary action of the inclined kiln to a second ball mill section. Here the product is converted to the oxide at high temperature. The balls greatly improve heat transfer. The oxide then passes through a cooling zone and is collected in water in a sealed tank. Steam and nitrogen oxides escape at the feed end and are then condensed. Dust that escapes with the gases may be captured in the condensing vapors, in which case aerosol problems would be minimized. No problems are foreseen in decontaminating the small quantities of noncondensable gases that will be evolved.

TABLE 1—Leaching of Fission Products from Fired Aluminum Oxide

Firing temperature (°C)	*Isotope*	*Distilled water*			*0.1N HNO_3 leach*		
		Leach time (days)	*% Leached*	*Al molarity in solution*	*Leach time (days)*	*% Leached*	*Al molarity in solution*
350	Cs^{137}	5	80.0	0.058	5	86.0	0.111
350	Sr^{90}	5	61–65		5	70	0.07
350	Ce^{144}	27	81.4		52	80–90	0.36
350	Ru^{106}	27	3.5		52	7.0	0.464
650	Cs^{137}	4	90.5	0.0028	2	99.5	0.074
650	Sr^{90}	4	0.15–0.35	0.007	4	46–66	0.14
650	Ce^{144}	27	1.1		52	80–90	0.288
650	Ru^{106}	27	0.5		52	25–30	0.36
950	Cs^{137}	1	93.5	0.0014	1	100	0.002
950	Cs^{137}	17	98.5		32	100	0.072
950	Cs^{137}	18	89		33	89.9	0.062
950	Sr^{90}	1	0.22	0.004	1	25	0.009
950	Ce^{144}	27	0.05		52	25–30	0.074
950	Ru^{106}	27	1.5		52	7–8	0.058
950	Mixed	17	20.5		32	60	0.04
950	fission				21	60†	0.148
950	products				47	36‡	0.07

† 6*N* acid used. ‡ 0.06*N* acid used.

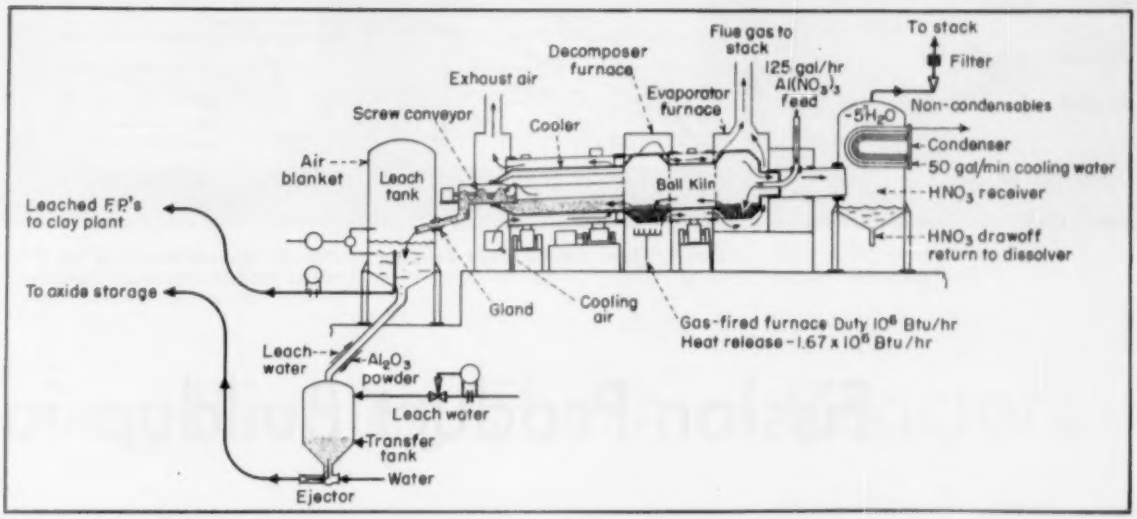

FIG. 2. Design of ball mill-kiln for concentrating fission products in Al_2O_3, produced from $Al(NO_3)_3$ content of waste

Equipment for Zr wastes. Emphasis is being placed on developing equipment for zirconium fluoride wastes.

Since nitrogen oxides and hydrogen fluoride are evolved at elevated temperatures, the corrosion problem is much more serious than for the aluminum waste. Otherwise equipment problems are much the same.

Economics of Treatment

The process using montmorillonite clay for ultimate disposal is designed to insure that dangerous fission products will not at some future time become free chemical agents in the natural environment and, therefore, be able to take part in the life cycles of plants and animals. Although the process is not unlimited in its practical application, it would always be subject to wider use as improved methods of pretreatment were devised. No departure from the basic approach to the problem would be needed, however. Figure 3 shows pretreatment schemes. A post-treatment of the clay-bed effluent is needed to fix Ru^{106}. The Ru^{106} concentrate, formed by evaporation, is fused in glass or ceramic bodies.

There is widespread agreement that some longer-lived fission products, notably Cs^{137} and Sr^{90}, may be considerably in demand as β- and γ-sources, but economic incentives and the comparison of total demand to total supply cannot now be foreseen. In any event the temporary use of the long-lived products will in no sense alter the basic

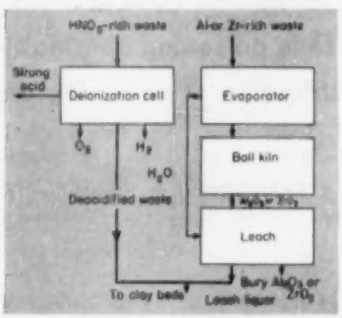

FIG. 3. Two pretreatment methods could be used before clay adsorption

problem of ultimate disposal. It is important that in developing methods for extracting fission products in the interests of short-time use, we do not complicate the more serious and inevitable problem of ultimate disposal.

Although economic factors are important in determining the feasibility of any disposal method, they should not be allowed to predominate for their own sake. It may well be that once economic factors are considered more comprehensively, they will be decisive in the higher interests of environmental safety. This is simply because they so practically reflect the long-range problems and responsibilities that accompany ownership of radioactive byproducts of a nuclear power industry.

In short, the soundest approach to practical economics in waste disposal will probably be in processes that promise to solve the disposal problem once and for all.

* * *

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TABLE 2—Leaching of Fission Products from Combined Zr and Al Oxides

Hydrolysis temperature (°C)	*Isotope*	*Distilled water*		*0.1N HNO_3*	
		Days leached	*% Leached*	*Days leached*	*% Leached*
700	Cs^{137}	6	64.2	6	65.5
700	Cs^{137}	6	44.2	6	61.2
700	Sr^{90}	6	23	7	61
700	Sr^{90}	6	21	7	61

Here's how fission products build up with burnup

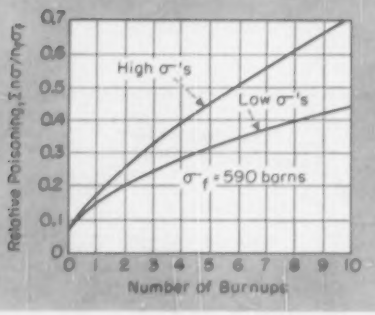

FIG. 1. Total fission-product poisoning for U^{235}

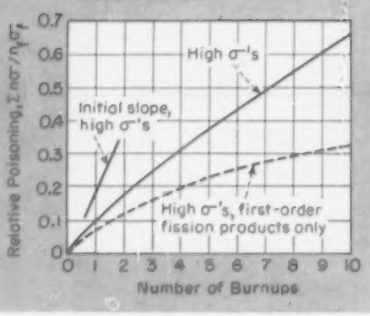

FIG. 2. Neutron poisoning for all U^{235} fission products except Xe^{135} and Sm^{149}

Fission-Product Buildup in

Fission-product poisoning in a thermal reactor after prolonged operation is evaluated from available data on fission yields and cross sections of U^{235} and U^{233}. Also, calculations are made of the decrease in poisoning obtainable by removal of fission-product gases and of the elemental distribution of poisoning and contamination

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POISONING CAUSED BY stable fission products is of great importance in the design and feasibility of long-burning thermal reactors with low enrichment fuel. These reactors are of increasing interest for central-station power applications. They include reactors of both the U^{235} and the U^{233} cycles, and of both heterogeneous and homogeneous design. The fuel rods of the heterogeneous reactors are expected to operate up to exposures of 10,000 Mwd/ton and above. The homogeneous reactor may utilize fuel replenishment during operation and run to even higher exposures before fission products are removed. In both heterogeneous and homogeneous types, the total fissions that occur in the active region before processing may exceed the original number of fissionable atoms. Then, poisoning by stable fission products is important.

Based on the best data available on cross sections and yield curves for the fission products, the neutron poisoning for a thermal reactor is calculated for continuous operation up to 10 burnups of the original fuel for a reactor operating with constant fission rate and fuel concentration. This corresponds physically to a homogeneous reactor in which one breeds or adds fissionable material at the same rate as fuel is removed by fissioning and radiative capture, and in which burnable poisons or poison control rods are used at startup to replace the poison to be formed later by the fission products. This hypothetical case represents an approximation to many possible reactors.

The fission-product poisoning is calculated separately for each stable fission-product isotope, thus permitting determination of the contributions to the poisoning and the number of foreign atoms in the fuel due to each specific element. The results are given in terms of relative poison, i.e., relative to the fission cross section of the fuel considered. By this value, one means the fraction of the neutrons absorbed by the fission products compared to the fraction of the neutrons absorbed by uranium to give fissions. The reactivity loss is proportional to this value of relative poisoning, the constant of proportionality depending slightly upon the design of the reactor. This con-

TABLE 1—Ranges of Unknown Cross Sections

Fission product	σ_{max} (*barns*)	σ_{min} (*barns*)
Kr^{85}	15	0
Sr^{86}	12	1.3
Zr^{93}	6	0
Ru^{100}	16	0
Ru^{101}	12	0
Pd^{104}	40	0
Pd^{105}	18	0
Pd^{106}	15	0
Pd^{107}	750	0
Pd^{110}	30	0.4
Cd^{110}	750	0
Cd^{111}	750	0
Cd^{112}	750	0.03
Xe^{128}	5	0
Xe^{130}	5	0
Xe^{132}	5.2	0.2
Xe^{134}	5.2	0.2
Cs^{137}	2	0
Sm^{148}	500	0
Sm^{150}	500	0
Gd^{156}	750	0

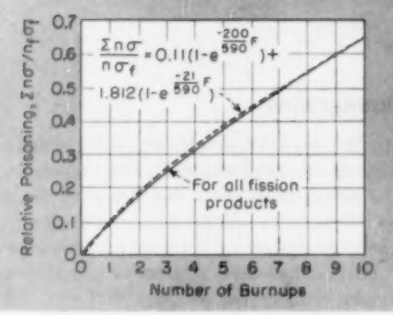
Relative Poisoning, $\Sigma n\sigma/n_f\sigma_f$
$\frac{\Sigma n\sigma}{n\sigma_f} = 0.11(1-e^{-\frac{200}{590}F}) + 1.812(1-e^{-\frac{21}{590}F})$
For all fission products
Number of Burnups

FIG. 3. Fit of equation for two hypothetical fission products to total poisoning for all fission products except Xe^{135} and Sm^{149}

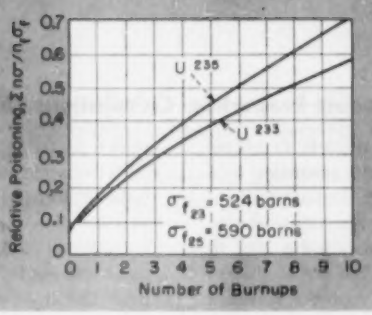

FIG. 4. Comparison of total fission-product poisoning from U^{235} and U^{233}

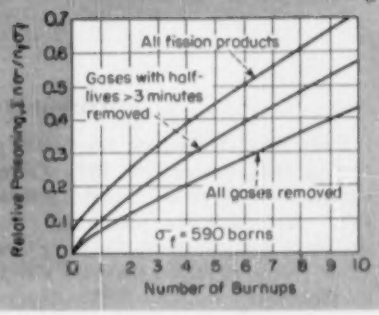

FIG. 5. Effect of gas removal on fission-product poisoning for U^{235}

Long-Burning Thermal Reactors

stant is usually about one-half; that is, a relative poison of 0.5 means 25% reactivity loss.

Assumptions

The method and equations used here are given under "Fission-Product Properties, Calculations, Assumptions." Cross sections used, as well as the fission-product yields, are as reported in the literature (*1*, *2*, *4*), with ranges of unknown cross sections as shown in Table 1. Important assumptions are: (a) constant fission rate and fuel concentration; (b) thermal flux of 10^{14} n/cm²/sec (necessary to define relative stability of the fission products); (c) absorption of neutrons by short-half-life fission products is negligible; (d) fission products transformed less rapidly by radioactive decay than by neutron capture in the assumed flux are considered to be stable; (e) thermal-column measurements of fission-product cross sections are equivalent to pile cross sections when the latter are not available; (f) no fission products are removed from the core.

Results

Figure 1 shows the relative fission-product poisoning for U^{235} as a function of burnup. The poisoning is expressed relative to the fission cross section of U^{235}. The upper and lower lines on the graph represent the poisoning calculated for maximum and minimum values of the unknown fission-product cross sections.

It is significant that over 70% of the spread between these curves is due to the uncertainty in the cross sections of Sm^{148} and Sm^{150}, which are both assumed to be between 0 and 500 barns.

TABLE 2—Distribution of Fission Product Poisoning by Elements

Fission product	*0.1 burnup* (%)	*1.0 burnup* (%)
Xe^{135}	70.95	35.6
Sm^{149}	13.98	7.0
Other rare earths	10.69	35.6
Technetium	1.55	8.0
Other rare gases	1.03	4.76
Rhodium	0.69	3.48
Cesium	0.40	2.10
Molybdenum	0.18	1.06
Others	0.53	2.40

TABLE 3—Fission Product Poisoning Distribution by Elements*

Fission product	*0.1 burnup* (%)	*1.15 burnup* (%)
Rare earths	70.2	61.0
Technetium	10.1	13.7
Rare gases	6.7	8.2
Rhenium	4.4	6.0
Cesium	4.0	5.4
Molybdenum	1.2	1.8
Others	3.4	3.9

* Sm^{149} subtracted; Xe^{135} decayed to Cs^{135}.

One important uncertainty recently has been resolved by an experiment (*3*) that found the cross section of the abundant fission product Zr^{93} to be less than 6 barns, a much smaller value than the 750 barns that had previously been estimated for the upper limit.

The values of relative fission-product poisoning given in Fig. 1 include the poisoning of Xe^{135} and Sm^{149}, which have extremely high cross sections. These isotopes account for the rapid initial rise in relative poisoning to 0.0778, but, due to their high cross section, they both saturate very rapidly and, by 0.06 burnup, are essentially constant poisons. In discussing the variation of fission-product poisoning, these isotopes are usually treated as constant poisons and are not included in the value of the variable fission-product poisoning. If this is done, Fig. 2 is obtained. The initial slope for the variable poisons is then 100 barns per fission with no appreciable poison being formed immediately on startup. The curve deviates considerably from linearity and within 2.1 burnups the poisoning is only 50% of the linearly extrapolated value. Note that this curve is based only on the maximum values for the unknown cross sections. All discussion here is based on the more conservative poisoning curve calculated from the maximum values of the unknown cross sections.

To illustrate the contribution made to the relative poisoning by the higher order fission products (new products formed by fission-product capture of neutrons), Fig. 2 also shows the relative poisoning for first-order fission products only. Thus, the difference between the curves represents the poisoning of higher order fission products. These curves show that although the higher order fission products are negligible contributors to the poisoning at low burnup, above one burnup they become significant, and at 10 burnups the higher order products have increased the first-order poisoning by 100%. It is the higher order products that cause the total neutron poisoning to rise

Fission-Product Properties, Calculations, Assumptions

When uranium fissions, two fission products of atoms varying in mass from 72 to 160 are formed according to a statistical distribution. Many of these fission products have short half-lives, producing fission-product chains similar to the one shown for mass number 91 in Fig. 6. These chains, of which there are about 70, are identified by their mass number. Although many of the isotopes in a single chain may be formed directly in fission (the approximate fraction is shown by the thickness of the arrows), it is usually possible to measure only the amount of the relatively stable atoms, and in this way obtain the value of percent yield for an entire mass chain. In ref. (4) these percent yields are listed for the various chains, for both U^{233} and U^{235}. Our values are obtained from a smooth curve fitted to the available data on fission-product yields, this curve adjusted to give a total percent yield of 200%.

In this calculation, the atoms in each chain are assumed to decay instantly to a relatively stable fission product. To define stability reasonably, a neutron flux of 10^{14} n/cm²/sec is assumed and an unstable isotope is defined as one that decays to a greater extent than it absorbs neutrons. Any isotope with cross section so high that the reverse happens is considered as stable. Thus, Xe^{135} with a half-life of only 9.2 hr is considered stable since its cross section of 3.5×10^6 barns means that, at the flux assumed, 94% of the disappearances of Xe^{135} are due to neutron absorption and not decay. Isotopes with half-lives of 20 yr or longer are assumed to be stable regardless of how low their cross sections are.

The first relatively stable fission product in each chain is called the primary fission product. Naturally, it can absorb a neutron—how quickly depends on its cross section for thermal neutrons. On absorbing a neutron, it becomes a new isotope of the same element, one mass unit larger (for a typical case, see Fig. 7). In many cases, this new material will decay to another isotope, but, whether it does or not, a new fission product capable also of absorbing neutrons is formed. This new atom is called a "second-order" fission product. It, too, can absorb a neutron to give a "third-order" fission product, and thus neutrons are continually absorbed until a low-cross-section isotope is obtained. In the 149 mass chain, the cross sections of the different-order fission products are sufficiently high that even the tenth-order fission product would be present in a long-burning reactor.

The neutron cross sections for the individual fission products are given in Refs. (1 and 2). In the case of some isotopes, where accurate values for cross section are not known, maximum and minimum values are assumed as shown in Table 1. Values of cross sections were obtained both from pile measurements and thermal-column measurements. Since the absorptions from the low-lying resonance region in a thermal-pile spectrum are not generally known, no attempt to get these cross sections on a common basis was made. Although there is some error introduced here, the cross section used should compare well with the actual cross sections in an average thermal-reactor neutron spectrum.

Burnup, F, is defined as the number of fissions that have occurred divided by the number of fissionable atoms originally in the core of the reactor. Thus, in a homogeneous reactor with a constant critical mass of 5 kg, two burnups represent the fission of 10 kg of uranium.

The equations used for the calculations of the poisoning for each individual isotope are obtained by simple integration of the flux equations

$$(dn_1/dt_1) = y\phi n_f\sigma_f - \phi n_1\sigma_1$$
$$(dn_i/dt) = \phi n_{i-1}\sigma_{i-1} - \phi n_i\sigma_i$$

where n_f = concentration of fissionable fuel (atoms/cm³), n_1 = concentration of first-order fission products (atoms/cm³), n_i = concentration of ith-order fission products (atoms/cm³), t = time (sec), y = yield in fission, ϕ = neutron flux ($cm^{-2}\ sec^{-1}$), σ = absorption cross section (cm²), σ_f = fission cross section (cm²).

The relative poisoning for a first-order fission product is then

$$(n_1\sigma_1/n_f\sigma_f) = y(1 - e^{-\sigma_1 F/\sigma_f})$$

For a second-order product

$$\frac{n_2\sigma_2}{n_f\sigma_f} = y\left[1 - \frac{\sigma_2 e^{-\sigma_1 F/\sigma_f}}{(\sigma_2 - \sigma_1)} - \frac{\sigma_1 e^{-\sigma_2 F/\sigma_f}}{(\sigma_1 - \sigma_2)}\right]$$

and at higher orders, additional terms are added to the equation. From these equations, the relative poisoning from each mass chain, and for as high an order fission product as are important, are calculated. These separate poisons are then added together for any given number of burnups. Thus, the fission-product neutron poisoning was calculated at 0.1, 0.3, 1.0, 2.0, and 10.0 burnups for U^{233} and U^{235}.

Poisoning due to the heavy nuclides produced by radiative capture in U^{233} and U^{235} were not included with the fission-product poisoning. Since the net poisoning is reduced by the generation of new fissionable fuels produced by successive neutron capture, the effect of including this poisoning in the total fission-product poisoning would be very small.

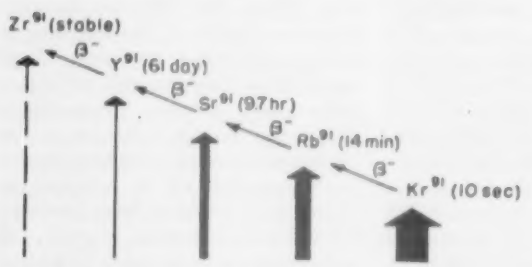

FIG. 6. Fission-product chain of mass 91

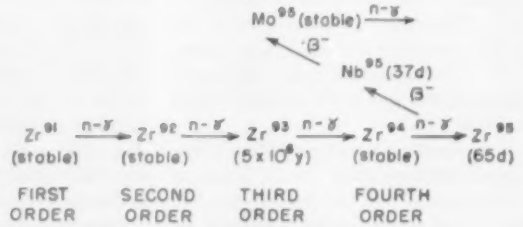

FIG. 7. Formation of higher order fission products

and not saturate at higher burnups.

It is sometimes useful to have the curve for the total variable fission-product poisoning in equation form. One equation* that fits this curve sufficiently well above 0.3 burnup is shown in Fig. 3, where F is the number of burnups. This equation represents the poisoning of two hypothetical fission products, one having a yield of 11% and a cross section of 200 barns and the other having a yield of 181.2% and a cross section of 21 barns. This accounts for 192% of the fission products, the other 8% being accounted for by Xe^{135} and Sm^{149}, which were subtracted from the total relative poisoning.

The relative fission-product poisoning of fissionable materials is important in comparing reactor types. Available information for Pu^{239}, which is less adequate than desirable, indicates the fission yields should be similar to those for U^{235} in the important rare-earth region (4). Because of the higher fission cross section of Pu^{239}, its fission products should cause about 20% less relative poisoning than does U^{235}. U^{233} seems preferable to U^{235} because of lower fission yield in the rare-earth region. Explicit calculations for U^{233}, given in Fig. 4, indicate about 19% less relative poisoning than for U^{235}.

Distribution by Element

From the calculations, the distribution of the neutron poisoning by each specific element can be determined. This shows which elements it is most important to remove so as to reduce poisoning most effectively. In Table 2, the distribution by individual elements is shown for 0.1 and 1 burnups. It is seen that Xe^{135} and Sm^{149} are the most important poisons. However, since both these isotopes saturate so rapidly after reactor startup, except possibly by continuous rapid fission-product removal in a homogeneous reactor, there is little chance for their elimination. Even though they could be completely removed in a conventional reprocessing cycle, after the reactor has started they would soon have built-up to the same extent as before reprocessing. The distribution of the remaining fission products is shown in Table 3. The other rare earths form the major part of the remaining fission-product poisoning; thus, a process that removes the rare earths and gaseous fission products will greatly reduce the poisoning. If neutron conservation is extremely important, as may be the case in special breeders, then technetium, rhodium, cesium, and molybdenum are next in importance to the rare earths, and with the rare earths and rare gases make up 99% of the fission-product neutron poisoning.

* H. Hurwitz, Jr. first suggested the usefulness of this representation.

TABLE 4—Atomic Percent of Elements

Fission product	*0.1 burnup* (%)	*1.0 burnup* (%)
Rare earths*	24.4	24.5
Rare gases	16.2	16.2
Zr	15.0	15.0
Mo	12.5	12.5
Cs	6.4	6.4
Ru	5.4	5.8
Sr	4.4	4.4
Te	4.0	3.6
Ba	3.2	3.2
I, Br	0.8	0.7
	92.4	92.3
Other elements	7.6	7.7
	100.0	100.0

* Distribution of specific rare-earth elements at 0.1 burnup is: Nd, 9.9%; Ce, 6.0%; La, 3.1%; Pr, 3.0%; Pm, 1.1%; Sm, 0.7%; Eu, 0.5%; Gd, 0.1%; for a total of 24.4%.

Since gaseous fission products might be removed relatively easily and continuously in a homogeneous reactor, it is of interest to see how much the poisoning could be reduced by removing the fission gas. In addition to removing Xe^{135}, which is a major poison, this process also might remove unstable isotopes of xenon, krypton, iodine, and bromine, which are not serious poisons themselves, but which decay to form isotopes of significant cross section. For example, Xe^{133} decays to form Cs^{133}. Although the xenon has a very low cross section, its removal prevents the production of a higher cross section daughter. Thus, the effect of the removal of these gases is greater than their fraction of the poisoning in Table 3.

Two cases of gas removal have been considered and a curve for each case is plotted in Fig. 5. The first case considers that all gases regardless of their half-lives are removed from the core. The second case assumes that only stable gaseous isotopes or gaseous isotopes with half-lives of 3 minutes or longer are removed. These curves show that a reduction in poisoning as large as 50% is possible, and that the more rapidly the gas is removed the larger is the reduction in poisoning.

An assumption was required concerning the fraction of various isotopes formed directly in fission. In mass chain 91, for instance, the amount of this chain that decays through krypton is not known. To give a value of *maximum* possible removal of poisoning, it is assumed that 100% of a mass chain would always pass through the gaseous member. For the case where only stable gases and gases with half-lives of over 3 minutes are removed, this is a reasonable assumption. However, for the very short half-life gases, such as Xe^{138}, the assumption that all the fission products decay through this member of the chain is optimistic.

In certain reactors, including fast reactors, fission-product poisoning is negligible compared to the poisoning due to the structural materials. The limit on the number of burnups the fuel elements can safely go to is set by the metallurgical properties of the uranium plus fission products—and not by the neutron poisoning of the fission products. Thus, distribution by elements of the fission-product atoms is of interest.

Table 4 gives the distribution of the elements present in the fission products for 0.1 and 1 burnups. The absolute number of all fission-product atoms is, of course, two times the number of fissions. While in the case of neutron poisoning, the rare earths were a major constituent, from the atomic fraction standpoint only about one-quarter of the atoms are rare earths, and one-quarter are gases, one-quarter noble metals, and one-quarter are more active metals. This means that a reprocessing system that will remove only two of these four classes will leave half the fission-product atoms in the U.

This estimate of the relative concentration of poisons at various burnups is useful in guiding metallurgical research on exposed fuel elements. Much of this investigation can be done on mocked-up fuel elements, that is, with uranium spiked with the proper amount of stable materials.

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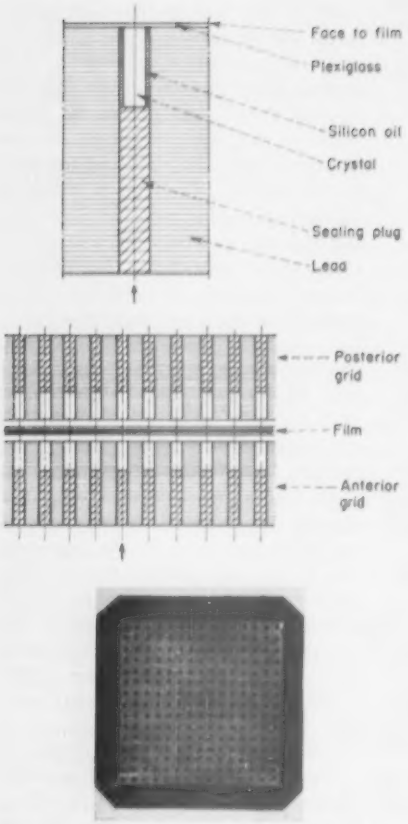

FIG. 1. Scintillation grid used in *in-vivo* localization

Scintillator Grid Localizes Gamma Emitters Photographically

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Four-minute exposures give good image of 10-μc/cm^3 I^{131} in a glass thyroid. This sensitivity is made possible by NaI crystals set in lead collimating grid

"IN VIVO" LOCALIZATION of a radioactive body is of great interest in medicine. Principal applications include the investigation of the shape, dimensions and functional topography of the thyroid gland; research into the distribution of radioactive bodies injected locally for a therapeutic purpose; encephalometry by isotopes for diagnosing brain tumors. This article describes a photographic technique using a collimating grid and NaI intensification, Fig. 1, for imaging radioisotope distributions.

Present Methods

Here are the principal methods used for localizing radioisotopes:

• Manual displacement, point by point, of a Geiger or a scintillation counter, both strongly collimated, enabling a *chart* to be drawn up formed of "isocount" lines (*1–8*).

• Automatic scanning with a suitably collimated scintillation counter, with a record of the number of counts per unit of time at regular intervals, either by moving a pen along a paper strip (scintigram, gammagram) (*9–14*), or by modulating the luminance of an oscillograph screen (*15–17*). Such devices enable an "image" to be obtained of the distribution of a radioactive body *in vivo*, but they involve a heavy movable member, a cumbersome mechanical device, and relatively complex electronic equipment.

• Two photographic methods are used:

1. By obtaining an image by means of a gamma-ray camera whose lens is a very-small-diameter hole in a lead wall (gamma-ray pinhole camera) (*18–20*). This method is limited by low geometrical efficiency—only a very small part of the quanta emitted by the source are used for making the image. It seems that in spite of strengthening by means of NaI crystals, one cannot, with a convenient exposure time, obtain an image from sources whose activity is less than 1 mc/cm^3. Apart from some particular cases, a concentration of this kind is scarcely compatible with utilization *in vivo*.

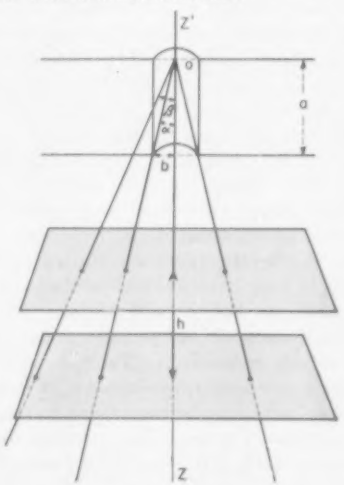

FIG. 2. Collimator geometry; source extends infinitely far in two dimensions

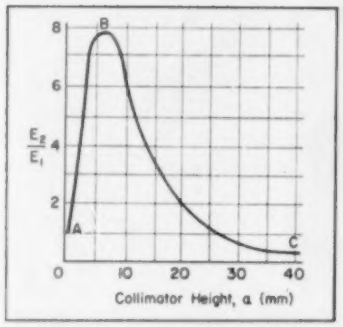

FIG. 3. Ratio of flux passing through collimator walls to that received directly, as function of collimator length

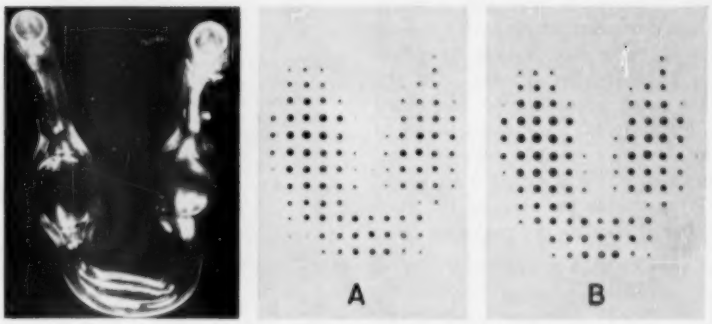

FIG. 4. Glass thyroid containing 400 μc and images obtained with double grid. Exposures were (a) 15 min with unsensitized film and (b) 4 min with film sensitized with mercury vapor

2. By using, like Skanse and Johansson (*21*) a lead grid of which each channel isolates a pencil of gamma rays coming from the corresponding volume element of the sources seen by the channel. These authors have been able to obtain images in a suitable exposure time with tolerable radioactive concentrations. They use a strengthening device consisting of a large-area NaI crystal 5-mm thick. The image is of poor quality, because the crystal is thick enough to diffuse the light.

Our photographic method also utilizes a lead grid, but combined with an *assembly* of strengthening devices so that an image of suitable sharpness can be obtained with a sufficiently short exposure time even with radioactive concentrations sufficiently weak to be biologically utilizable. With a scanning device, Mayneord and his collaborators (*15, 16*) have been able to obtain the image of the distribution of a radioactive body *in vivo* in the shape of a series of spots regularly spaced out whose photographic density is in keeping with a corresponding volume element of the radioactive source. We have endeavored to obtain images of this type by purely photographic means.

Collimator Design

Consider a cylindrical channel through a lead wall of height a and radius b facing an infinite homogeneous radioactive source of activity A μc/cm³ limited by two infinite planes perpendicular to the axis of the channel and a distance h apart (Fig. 2). The flux of photons in the center of the upper opening O of the channel is

$$E_1 = (3.7 \times 10^4 Ah/2)(1 - \cos\alpha) \quad \text{where } \tan\alpha = b/a \quad (1)$$

Actually, the point O is also subjected to the radiation that passes through the lead, outside the cone with summit at O and half-angle α. Presuming that we are dealing with a monoenergetic gamma radiation source the flux of these photons in the center of the upper opening O is

$$E_2 = (3.7 \times 10^4 Ah/2) \int_0^{\cos\alpha} e^{-\mu\left(\frac{a}{x} - \frac{b}{\sqrt{1-x^2}}\right)} dx \quad (2)$$

where μ is the linear absorption coefficient of the lead for the monoenergetic radiation.

This integral cannot be brought down to elementary algorithms and the various developments in series that we tried converge too slowly. The simplest method is to integrate numerically by Simpson's method.

We computed E_2/E_1 for several values of a and for the 364-kev radiation which represents 80.9% of the gamma rays of the spectrum of I^{131} (*22*), the isotope most used in medical work. We took b as being 1 mm; μ = 2.67 cm^{-1} by interpolation from a suitable table (*23*). The variation of E_2/E_1 as function of a is given in Fig. 3.

The portion AB of the curve is without interest, for it corresponds to large half angle α, therefore to poor geometric collimation. For a 10-mm thickness of lead (corresponding to a semi-opening α = 5.72 deg) 6.7 times more gamma photons pass through the lead than through the opening geometrically defined by the channel. It is only for a thickness of 25 mm that the number of photons passing into the geometrical opening is equal to that of the photons passing through the lead.

The table gives, for different thicknesses of lead, a, the half angle α of the cone defined by the geometry of the channel, and the half angle β of a cone corresponding to 75% of the total flux of photons received at O (Fig. 2). The

a (*mm*)	α (*deg*)	β (*deg*)
10	5.72	35
15	3.82	30
20	2.87	16
25	2.30	5
30	1.90	2.25
35	1.63	1.69*
40	1.43	†

* Practically 100% in 3 deg
† Practically 100% in 2 deg

table shows that the collimation is good for 30-mm thickness and excellent for 40 mm. It is only for thickness of lead of this order (in the case under consideration, the 364-kev ray of I^{131}) that there exists a direct correspondence between the flux of the gamma rays received at O and the concentration A of the activity of the body in the vicinity of that axis, independent of the distribution of radioactivity away from the axis of the channel.

These results are valid for a channel 2 mm in diameter. We state farther on why this dimension has been forced on us for practical reasons. They also deal with an infinite plane source. For a source of finite dimensions, the ratio E_2/E_1 is correspondingly smaller as the source is smaller. For sources of medium dimensions, the collimation conditions are a little less severe.

Exposure Times

According to Mayneord (*24*), we should supply an assembly of high-

speed radiological film and a high-voltage intensifier screen with a ~5-mr dose of ~100-kev X-rays to obtain unit photographic density. On the other hand, according to Mayneord and Sinclair (*25*) a pin-point source of 1 mc of I^{131} gives 2.25 r/hr at 1 cm. From this we deduce that 5 mr would be given by the radiation of I^{131} for a number of photons per unit area of

$$\frac{3.7 \times 10^7 \times 3{,}600 \times 5}{4\pi \times 2{,}250}$$

Let us consider an indefinite source limited by two parallel planes 2 cm apart and whose homogeneous activity is 10 $\mu c/cm^3$. We will use a 20 mm-thick grid with 2-mm-diameter channels. Equation 1 and Fig. 3 show that the number of photons per second and per unit of surface of the intensifier-film combination is

$$3.7 \times 10^4 \times 10 \times 0.00125 \times 3$$

If, for the spectrum of I^{131}, the screen intensifier-film combination had the same sensitivity as for 100-kev radiation, the exposure time required for obtaining unit blackening opposite each channel would be, in hours

$$\frac{3.7 \times 10^7 \times 3{,}600 \times 5}{4\pi \times 2{,}250} \times \frac{1}{3.7 \times 10^4 \times 10 \times 0.00125 \times 3{,}600 \times 3} \cong 5 \text{ hr}$$

Experience shows that the screen intensifier-film assembly (Sinegran ultra and Kodak Regulix) is decidedly less sensitive to the radiation of I^{131} than to 100-kev X-rays. The exposure time for obtaining unit photographic density is experimentally, with the preceding source, about 15 hr. (Developing with Radio-Kodalk developer at 22° C for 7 min.)

Imagine a 40-cm^3 thyroid about 2 cm thick with a fixing rate of 50%. Ingestion of 800 μc would thus give, supposing the distribution of the I in the thyroid to be practically homogeneous, a concentration of 10 $\mu c/cm^3$. According to the foregoing, it would require an exposure time of about 15 hr to obtain an image of the thyroid with about unit photographic density in the spots.

This exposure time not being acceptable, we have thought in preliminary work (*26*) of increasing the sensitivity of the radiological film by sensitizing it with mercury vapor. But sensitizing at 24° C and 50% humidity in a perfectly air-tight zone only increased sensitivity by a factor of 4 which enables a suitable image to be obtained with 3-hr exposures with concentrations of about 10 $\mu c/cm^3$. See Fig. 4.

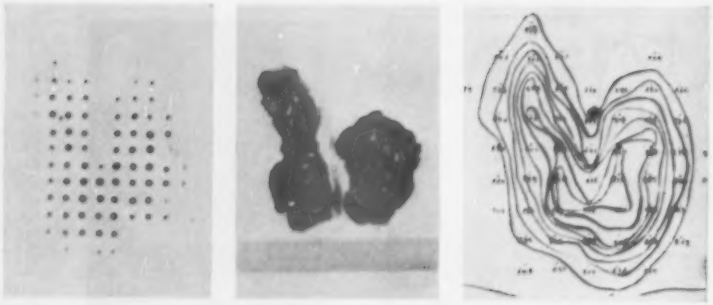

FIG. 5. Here is an image of a thyroid obtained with a patient who had ingested 300μc with a fixing rate of 50% and 20-min. exposure on a film sensitized with mercury vapor. This figure also shows the map obtained with a directional Geiger counter and the operatory piece after sub-total thyroidectomy. One will notice that the gammagraph gives a good representation of both lobes of the thyroid and specially stresses the presence of a narrowing in the middle of the right lobe

NaI Intensification

An exposure time of 3 hours being still much too long in medical practice, we tried to increase sensitivity by using, as an intensifying device, not an intensifying screen, but scintillators incorporated in the channels of the grid themselves, so as to retain the sharpness of the image. In view of what we have seen, as expressed in Fig. 3 and the table, it is not possible to fill the whole of the channel with the scintillator without the risk of having poor sharpness. Preliminary experiments have shown us that with a prismatic NaI(Tl) crystal 6 mm long, inserted in the end of a channel 2 mm in diameter and 18 mm long, being the end against which a radiological film is placed, the sensitivity was multiplied by a factor of about 30 as compared with our preliminary work.

The cutting of very numerous small crystals being a long, painful and delicate operation, we tried a liquid-scintillator solution of 5 gm/l of paraterphenyl in xylene. Even for a scintillator thickness of 1 cm, the low efficiency prevented a result distinctly better than that given by screens.

Calcium tungstate crystals have excellent yield but the fact that they do not crystallize in the cubic system makes cleavage in the simple form of small rectangular crystals difficult.

NaI, although hygroscopic, crystallizes in the cubic system and easily cleaves at right angles. We have thus prepared crystals of NaI(Tl) in the form of rectangular parallelepipeds 6 mm long and square in section inscribed in the circle 2 mm in diameter. Cutting is done by cleaving in an air-tight glove box, in a phosphoric-anhydride-dried nitrogen atmosphere. Carefully made cutting-shapes enable the crystals to be cleaved to the required dimensions reproducibly.

The crystals used for a grid all came from a single crystal that was as homogeneous as possible. A small trial grid enabled the crystals to be tested photographically in groups of 30 on a large flat radioactive source. All those that for various reasons (difference in cutting dimensions, lack of homogeneity, etc.) do not give a dark spot identical to or closely resembling that of a crystal used permanently as a standard, are eliminated. Thus, by exercising patience, it is possible to obtain enough similar crystals to make a grid. This question of homogeneity of photographic efficacy of the crystals, which is obviously fundamental for obtaining suitable images, is one of the greatest difficulties in producing a grid.

For that reason, we have been led to make two experimental grids of small dimensions, 18 mm thick, whose network comprises 15 rows each with 15 holes, making 225 holes, each hole being in a corner of a square with 5 mm sides. Each channel has a diameter of 2 mm. The two grids of lead with 10% antimony were drilled together. Radiological film is placed between the two grids, separated from each channel by a sheet of Plexiglass 0.8 mm thick, hermeticaly sealed against the lead with araldite. The channels are filled with silicone oil dehydrated by heating in a high vacuum. The silicone oil

provides optical contact between the Plexiglass and the face of the crystal in addition to preserving the crystals. Each crystal is kept in position in its channel by means of a sealing-plug. Lastly, the two faces of the double grid away from the film are masked by a sheet of aluminum sealed to the lead with araldite. The diagram and photograph of Fig. 1 show the assembly.

Experiment has shown that this double-grid device, inspired by analogy with intensifier screens, enables the sensitivity of the device to be increased by 50%. A supplementary grid, 1 cm thick, drilled at the same time as the first two, allows more collimation of the grid turned towards the source.

The diameter of 2 mm taken for the channels is obligatory, because it is sufficiently small to afford a density of holes compatible with a suitable image, and sufficiently large so that the crystals incorporated can be cut without too much difficulty.

Results

Figures 4, 5, and 6 typify results achieved thus far. The image gives a satisfactory picture of the object. Two factors, to which we shall refer later, must be modified so as to improve the quality of the image obtained:

a) The collimation produced by the thickness of 18 mm of our experimental grid is still imperfect. The sensitivity of the device is such that, by reason of the facts demonstrated by Fig. 2 and the table, if collimation is not sufficient, the crystals which are outside the projection area of the source on the grid give a spot of appreciable density that reduces the sharpness with which the image comes out.

b) The spacing of the channels made on our experimental grid is still too great. Nevertheless, the results obtained show that with a device of this kind, it is possible, in the case of I^{131}, to obtain an image in short exposure times with aqueous physiological doses.

Future Possibilities

The spacing of the channels, which is relatively great on this experimental grid, reduces the sharpness of the images. By improving the technique of producing crystals, we hope to obtain a large sized grid, thicker, and consequently better collimated, whose network of channels would be appreciably closer. We expect to compensate for the loss of sensitivity due to the increase in collimation (which is necessary, if the network of channels is closer), by increasing the light-collection factor of the crystals. The order of magnitude of the latter, in the case where the polished surface crystals are, as in our experimental grid, plunged into a lead-wall zone and bathed in silicone oil, is difficult to gage. We believe that we may be able to increase it by making a housing wall for the crystals with a high diffusion factor for the luminous fluorescent quanta.

Image amplification offers further possibilities. Benjamin and Copeland (*18*) had already advocated associating a pinhole camera with an electronic image amplifier, and recently, Mortimer, Anger and Tobias (*27*) have achieved a device of that kind. Following recent preliminary research work (*28*) it has appeared to us to be possible to associate a grid with an image amplifier. The crystals could be in optical contact with the photocathode of an image amplifier without a radioscopic screen. An optical system of weak resolution (which, for an image of this kind, is not very important), but with a large aperture, would enable the greater part of the light emitted by the receiving screen of the image amplifier to be recovered. A new amplification factor to the extent of 100, would then be possible. This could be used to improve resolution.

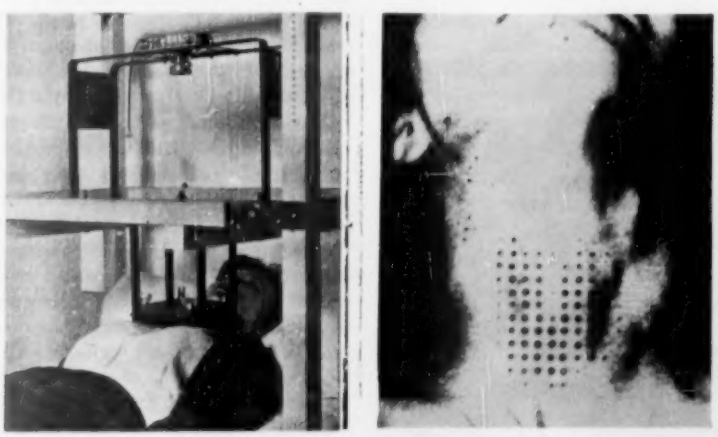

FIG. 6. This is a device conceived for securing the gammagraph of a human being's thyroid and the exact photographic superimposition of the gammagraph with the corresponding anatomical area. Figure 7 at right shows the result of this superimposition.

Using a double grid in each of two rectangular planes, it is possible to obtain two simultaneous gammagraphs of the thyroid in two rectangular planes, which enables the volume of the gland to be ascertained with a certain amount of accuracy

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LIQUID SCINTILLATORS—I

Pulse Height Comparison of Primary Solutes

Here's how 102 selected organic compounds in toluene rank in scintillating ability. The implied relationships between structure and scintillation are explored

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THIS ARTICLE presents information on the maximum pulse heights obtained with each of 102 different organic solutes in toluene as a solvent. Since the pulse height varies as a function of concentration, the concentration at which the maximum relative pulse height obtains is also tabulated. The ratio of pulse heights as measured with titanium dioxide and aluminum reflectors is also given since this is an index of the spectrum emitted by the scintillator. Background information, measurement techniques, and conclusions as to the relation between chemical structure and scintillation ability are presented.

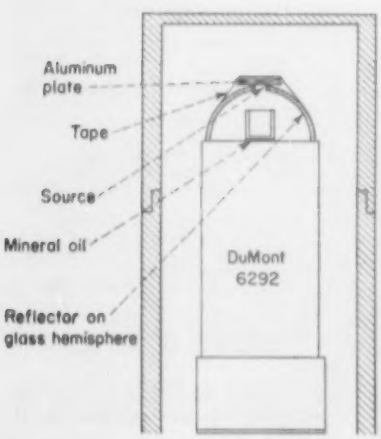

FIG. 1. Source-scintillator-photomultiplier assembly

FIG. 2. Liquid scintillator about to be tested with aluminum reflector

Pulse-Height Measurement

All of the scintillation measurements were carried out with a pulse-height analyzer deriving its input signals from a DuMont 6292 photomultiplier. The scintillator solution to be analyzed was pipetted into a glass beaker with a 1-ml capacity. This beaker was then placed on the flat cathode of the erect photomultiplier with a few drops of mineral oil between to insure good optical coupling. The solutions were excited with 624-kev internal-conversion electrons from Cs^{137} (actually from 2.6-min. Ba^{137} in secular equilibrium with Cs^{137}). The resulting line spectrum was electronically analyzed and the discriminator voltage for its peak was recorded as the pulse height.

Curves of pulse height versus concentration of the various solutes in toluene were run using an evaporated-aluminum reflector. In another study, each solute, at a concentration of 3 gm/l in toluene, had its pulse height measured with *two* reflectors, aluminum

and titanium dioxide. A standard solution of 3 gm/l of 2,5-diphenyloxazole in toluene was used throughout the study as a standard and all results are expressed as relative pulse heights versus this solution.

Figure 1 shows the relative placement of the source, reflector, scintillator and photomultiplier in the detector portion of the pulse height analyzer. Figure 2 is a photograph of the reflector and source being placed over the scintillator-containing beaker on the flat cathode end of the photomultiplier.

Chemicals tested were of the highest obtainable purity. A majority of the compounds were synthesized at Los Alamos and were recrystallized until they were analytically pure; that is, until the microanalytical data for the elements agreed with the theoretical values. This set a criterion of purity that was adhered to for all the other compounds.

Results

The experimental results are listed in the table on p. 40, giving the compound name, followed by its maximum relative pulse height and the concentration at which this was reached. The final column of the table lists the relative-pulse-height ratio from titanium dioxide and aluminum reflectors. The results are listed in the order of decreasing maximum relative pulse height, where, for more than one compound with the same pulse height value, the results are listed in increasing value of concentration. Compounds 83 through 90 have no listed values in the last column because these numbers, although measurable, have much too great statistical errors to be considered.

Discussion

Liquid scintillation solutes are a select class of compounds notable because a significant fraction of their excited molecules lose energy by light emission. As a solvent such as toluene is made to contain small increasing concentrations of a scintillation solute, the measured pulse height increases by virtue of more photons emitted from more molecules present.

One condition which may abruptly terminate the rise of pulse height with concentration is that the compound may have a limited solubility in the scintillation solvent. Such compounds exist and are exemplified by *p*-ter-

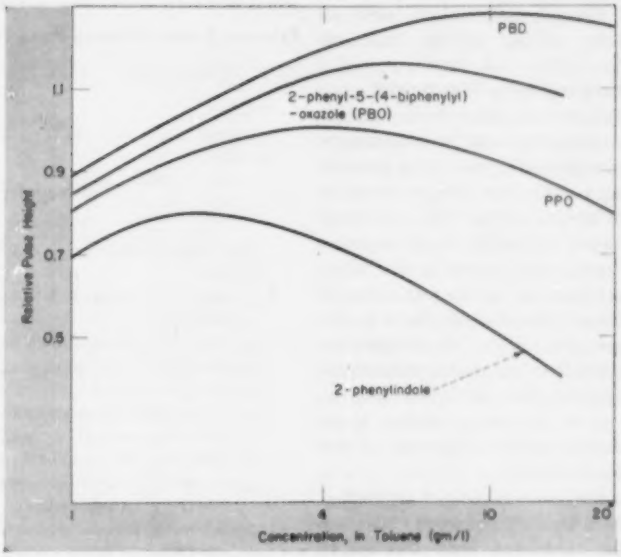

FIG. 3. Representative concentration curves. Self-quenching is least for top curve and increases with each lower curve

How Scintillation Ability Relates to Structure

The early history of the liquid scintillator program of the Biomedical Research group at Los Alamos featured the synthesis of many new compounds for study as liquid scintillation solutes (1). The initial guide for the preparative work was obtained from Kallman's information (2) which showed that p-terphenyl stood alone as an effective liquid scintillation solute in a great number tested. Its chemical relative, p-quaterphenyl, was rather insoluble in toluene but still had remarkable scintillation properties in its ability to function as a secondary solute. This suggested that one might take advantage of the improvement both in quantity of light emitted and the spectrum of that light resulting from a molecule with four rings rather than one with three, providing insolubility could be removed as a restriction.

Our first observation of a new series of solutes was with 2-phenyl-5-(4-biphenylyl)-oxazole which was much more soluble than p-terphenyl and which proved on preliminary measurements to be a better scintillator. Since that time almost all of the compounds which have been made have adhered to the structural criterion that they should be built of simple aromatic rings linked in a linear manner to allow continuous conjugation throughout the molecule. The aromatic ring systems which have been incorporated in potential scintillation solutes are benzene, naphthalene, furan, pyrrole, thiophene, oxazole, imidazole, thiazole, 1,3,4-oxadiazole, 1,3,4-thiadiazole, pyridine, pyrazine, pyridazine, indole, benzoxazole and benzothiazole.

Attempts to make sweeping generalizations as to the relationship between chemical structure and scintillation ability have consistently failed because of the diverse processes which contribute to this ability. A few conclusions are apparent:

1. *Linkage of four rather than three rings in a molecule yields a better scintillator, partly because of its longer wavelength spectrum.*
2. *Four and five-ring compounds have sufficient solubility for scintillation applications when they incorporate heterocyclic ring systems such as oxazole.*
3. *Generally beneficial ring systems are benzene, naphthalene, furan, pyrrole, oxazole, 1,3,4-oxadiazole, pyridine, indole and benzoxazole. Poor ones are thiophene, thiazole, 1,3,4-thiadiazole, pyrazine, pyridazine and benzothiazole.*
4. *Substituent groups causing no difficulty are methyl, methoxyl, fluoro and chloro. Undesirable ones are bromo, iodo, nitro and phenolic hydroxyl.*

phenyl, whose concentration curve is still rising steeply at its limit of solubility.

For those solutes with sufficient solubility, the concentration curve reaches a broad maximum and then proceeds to drop in pulse height. The process occurring in this part of the curve is termed "self-quenching," nonradiative de-excitation by molecules of the same kind. The concentration in the table which corresponds to the maximum in the relative pulse height curve is an indication of the degree of self-quenching. A small value of this concentration suggests that self-quenching is severe—it is operating earlier than usual to reverse the rising trend of the concentration curve.

The only generalizations regarding self-quenching which seem possible from the table are that the 1,3,4-oxadiazole and the benzene rings are associated with a much smaller degree of self-quenching than the pyrrole and indole rings and that most of the other ring systems fall in between.

Figure 3 shows some representative cases of different degrees of self-quenching. PBD contains three benzene rings and one 1,3,4-oxadiazole ring and exhibits the least self-quenching as evidenced by its peak falling at 10 gm/l. The second compound, PBO, is structurally quite similar to the first with an oxazole ring instead of the 1,3,4-oxadiazole ring. The result is a peak at 6 gm/l. PPO, with one less benzene ring than PBO, peaks at 4 gm/l and the compound with the greatest degree of self-quenching, 2-phenylindole, has its concentration curve peak at only 2 gm/l.

Reflector Effects

The values for maximum relative pulse height depend not only on the relative probability for the compounds to emit photons and on inherent probability of self-quenching, but also on the spectrum of the light which is emitted. This is due to the nature of the detector. The photocathode has a somewhat selective sensitivity curve which causes it to discriminate on a wavelength basis. Two compounds which yield the same number of photons may give considerably different measured pulse heights, because of the different degree of matching of their emission spectra to the photocathode sensitivity curve.

The two reflector systems, titanium

Primary-Solute Relative Pulse Heights

No.	Compound	Ref.	Max. rel. pulse ht.	Conc. (gm/l)	Pulse-ht. reflector ratio at 3 gm/l (TiO_2/Al)
1.	2-phenyl-5-(4-biphenylyl)-1,3,4-oxadiazole[c] (PBD)	1	1.28	10	1.03
2.	2-(4-methoxyphenyl)-5-(4-biphenylyl)-1,3,4-oxadiazole	1	1.24	7	1.04
3.	2-(4-methoxyphenyl)-5-(4-biphenylyl)-oxazole	1	1.19	6	1.13
4.	2-(4-biphenylyl)-5-phenyloxazole	1	1.18	8	1.13
5.	2-phenyl-5-(4-biphenylyl)-oxazole	3	1.16	6	1.13
6.	2-(2-naphthyl)-5-phenyloxazole	1	1.14	5	1.11
7.	2,5-di-(4-methoxyphenyl)-1,3,4-oxadiazole	1	1.11	8	0.97
8.	2,5-di-(2-naphthyl)-oxazole	1	1.08	5	1.17
9.	2-(1-naphthyl)-5-(4-biphenylyl)-oxazole	1	1.08	6	1.20
10.	2,5-di-(1-naphthyl)-oxazole	1	1.08	8	1.20
11.	2-(3,4-methylenedioxyphenyl)-5-phenyloxazole	4	1.07	5	1.05
12.	2,5-di-(2-furyl)-1,3,4-oxadiazole	1	1.06	4	0.94
13.	2-(4-methoxyphenyl)-5-(2-naphthyl)-oxazole	1	1.05	5	1.17
14.	1-methyl-2,5-diphenylpyrrole	5	1.04	3	1.05
15.	2,5-di-(1-naphthyl)-1,3,4-oxadiazole	1	1.04	6	1.13
16.	2-(2-fluorophenyl)-5-phenyloxazole	1	1.03	5	1.00
17.	2-(2-tolyl)-5-phenyloxazole	6	1.03	8	1.01
18.	2-phenyl-5-(2-naphthyl)-oxazole	3	1.02	4	1.11
19.	2-(4-methoxyphenyl)-5-phenyloxazole	6	1.02	7	0.94
20.	2,5-di-(4-tolyl)-1,3,4-oxadiazole	7	1.02	8	0.87
21.	2,5-diphenyloxazole[c] (PPO)	8	1.01	4	1.00
22.	2-(4-tolyl)-5-phenyloxazole	6	1.01	5	1.03
23.	2-phenyl-5-(1-naphthyl)-oxazole	6	1.01	6	1.19
24.	2,5-di-(4-chlorophenyl)-1,3,4-oxadiazole	1	1.01	7[a]	0.91
25.	2-(2-methoxyphenyl)-5-phenyloxazole	1	1.01	8	1.03
26.	2-(1-naphthyl)-5-(2-naphthyl)-oxazole	1	1.00	5	1.23
27.	*p*-terphenyl[c] (Φ_3)		1.00	8[a]	0.86
28.	2-(4-methoxyphenyl)-5-(1-naphthyl)-1,3,4-oxadiazole	1	0.99	7	1.10
29.	2,5-diphenylpyrrole	9	0.97	3	1.06
30.	2-(3-methoxyphenyl)-5-phenyloxazole	1	0.97	6	0.96
31.	2-(4-fluorophenyl)-5-phenyloxazole	1	0.96	5	0.97
32.	2-(4-methoxyphenyl)-5-(2-naphthyl)-1,3,4-oxadiazole	1	0.96	6	1.00
33.	2-(4-biphenylyl)-benzoxazole[d]		0.96	6	1.11
34.	2-(2-furyl)-5-phenyloxazole	1	0.95	3	1.03
35.	2-(3-chlorophenyl)-5-phenyloxazole	4	0.95	4	1.00
36.	2-phenyl-5-(2-furyl)-1,3,4-oxadiazole	1	0.94	4	0.91
37.	2-(2-pyridyl)-5-phenyloxazole[d]		0.94	5	1.07
38.	2-(4-chlorophenyl)-5-phenyloxazole	1	0.94	6	1.07
39.	2-(1-naphthyl)-5-phenyloxazole[c] (αNPO)	6	0.93	4	1.21
40.	2-(3-pyridyl)-5-phenyloxazole[d]		0.93	6	1.06
41.	2,5-di-(4-biphenylyl)-1,3,4-oxadiazole	1	0.92	1.5[a]	1.04[b]
42.	2-(3,4-dichlorophenyl)-5-phenyloxazole	1	0.92	5	1.04
43.	2,5-diphenyl-1,3,4-oxadiazole	10	0.89	15	0.89
44.	2,5-di-(4-biphenylyl)-oxazole[c] (BBO)	1	0.88	1.4[a]	1.17[b]
45.	2-(3-tolyl)-5-phenyloxazole	6	0.88	5	1.06
46.	2-(3-fluorophenyl)-5-phenyloxazole	1	0.87	4	1.02
47.	2,5-di-(2-naphthyl)-1,3,4-oxadiazole	1	0.87	7[a]	1.02
48.	2,5-diphenylfuran	11	0.86	2	1.04
49.	2-(2-chlorophenyl)-5-phenyloxazole	4	0.85	5	1.01
50.	2,5-di-(4-fluorophenyl)-1,3,4-oxadiazole	1	0.85	6	0.91
51.	2-phenylbenzoxazole	12	0.84	5	0.91
52.	2-phenyl-5-(1-naphthyl)-1,3,4-oxadiazole	1	0.83	5	1.04
53.	2-phenylindole	13	0.80	2	0.97
54.	1,4-di-[2-(5-phenyloxazolyl)]-benzene[c] (POPOP)	1	0.79	1.2[a]	1.23[b]

Primary-Solute Relative Pulse Heights

No.	Compound	Ref.	Max. rel. pulse ht.	Conc. (gm/l)	Pulse-ht. reflector ratio at 3 gm/l (TiO_2/Al)
55.	2-(4-pyridyl)-5-phenyloxazole[d]		0.79	4	1.04
56.	2-(1-naphthyl)-benzoxazole	*14*	0.79	5	1.09
57.	2-(2,4-dichlorophenyl)-5-phenyloxazole	*1*	0.79	6	1.04
58.	2,5-di-(2-thienyl)-1,3,4-oxadiazole	*1*	0.77	5	1.09
59.	5,5′-diphenyl-2,2′-bioxazolyl	*1*	0.76	1.0[a]	1.16[b]
60.	2-(2-naphthyl)-indole	*15*	0.75	2	1.06
61.	2-(ω-styryl)-5-phenyloxazole	*6*	0.71	2	1.16
62.	2-phenylphenanthroxazole	*16*	0.68	3	1.07
63.	2,3,4,5-tetraphenylpyrrole	*17*	0.61	5	1.11
64.	triphenyloxazole	*18*	0.61	6	1.07
65.	2-(1-naphthyl)-5-methyloxazole[d]		0.60	3	0.96
66.	2-phenyl-5-(2-naphthyl)-1,3,4-oxadiazole	*1*	0.59	4	1.01
67.	2-phenyl-5-(2-thienyl)-1,3,4-oxadiazole	*1*	0.59	9	1.00
68.	1,6-diphenyl-1,3,5-hexatriene[c]		0.58	1.3	1.08
69.	2-(4-biphenylyl)-indole	*19*	0.52	0.6[a]	1.12[b]
70.	tetraphenylfuran[c]		0.51	12	1.02
71.	5,5′-di-(2-naphthyl)-2,2′-bioxazolyl[d]		0.49	0.7[a]	1.20[b]
72.	2,5-di-(ω-styryl)-1,3,4-oxadiazole	*1*	0.47	2	1.16
73.	2-(3-bromophenyl)-5-phenyloxazole	*1*	0.43	4	1.09
74.	2-(2-thienyl)-5-phenyloxazole	*1*	0.41	5	1.08
75.	2,5-di-(4-bromophenyl)-1,3,4-oxadiazole	*20*	0.41	6[a]	0.90
76.	2-cyclohexyl-5-phenyloxazole	*1*	0.30	10	0.73
77.	fluoranthene[c]		0.30	25	1.21
78.	2-(4-bromophenyl)-5-phenyloxazole	*1*	0.28	5	1.03
79.	2,4,5-triphenylimidazole	*21*	0.27	0.6[a]	1.04[b]
80.	2,5-diphenylthiazole	*22*	0.23	5	1.13
81.	5,5′-diphenyl-2,2′-bi-1,3,4-oxadiazolyl[d]		0.22	0.7[a]	0.93[b]
82.	pyrene[c]		0.21	5	1.29
83.	2,5-diphenylthiophene	*9*	0.19	7	
84.	anthracene[c]		0.18	1.5	
85.	phenanthrene[c]		0.16	250[a]	
86.	1,1,4,4-tetraphenyl-1,3-butadiene[c]		0.12	20[a]	
87.	1,4-di-[2-[5-(4-biphenylyl)-oxazolyl]]-benzene	*1*	0.10	0.3[a]	
88.	chrysene[c]		0.09	5	
89.	1,4-di-[2-(5-phenyl-1,3,4-oxadiazolyl)]-benzene	*1*	0.09	0.2[a]	
90.	2-(2-bromophenyl)-5-phenyloxazole	*1*	0.06	3	
91.	2-(2-iodophenyl)-5-phenyloxazole	*1*	0.00		
92.	2-(3-iodophenyl)-5-phenyloxnzole	*1*	0.00		
93.	2-(4-iodophenyl)-5-phenyloxazole	*1*	0.00		
94.	2-(3-nitrophenyl)-5-phenyloxazole	*6*	0.00		
95.	2-(4-nitrophenyl)-5-phenyloxazole	*6*	0.00		
96.	2,5-diphenyl-1,3,4-thiadiazole	*23*	0.00		
97.	2-phenylbenzothiazole[c]		0.00		
98.	2-(2-hydroxyphenyl)-benzoxazole[c]		0.00		
99.	3,6-diphenylpyridazine	*24*	0.00		
100.	2,5-diphenylpyrazine	*25*	0.00		
101.	tetraphenylpyrazine[c]		0.00		
102.	1,5-diphenyltetrazole[f]		0.00		

[a] References are in bibliography at end of article.
[b] Solubility limit.
[c] Measured at the solubility limit.
[d] Now commercially available.
[e] Not reported previously.
[f] Supplied through the courtesy of Dr. Henry Gilman, Iowa State College, Ames, Iowa.
Supplied through the courtesy of Dr. Eugene Lieber, U. S. Naval Ordnance Testing Station, Inyokern, California.

dioxide and aluminum, are quite different in the shapes of their curves of reflectance versus wavelength. Aluminum is a consistently good reflector throughout the range of wavelengths encountered in the emission of scintillation solutes; whereas, titanium dioxide is a good reflector only above 4,000 Å. The ratio of pulse heights, obtained by dividing the titanium dioxide value by the aluminum value, should be higher for compounds emitting above 4,000 Å than for compounds emitting below. The relative-pulse-height reflector ratio as listed in the last column of the table should serve as an indication of the mean wavelength of emitted light. Those compounds emitting at longer wavelengths than PPO should give values greater than 1, and conversely, those of shorter wavelengths should give values of less than 1. A small amount of work carried out to date with measurements of scintillation spectra has shown that the indication given by this ratio is qualitatively correct.

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Next Month . . . Pulse Height Comparison of Secondary Solutes

Liquid Scintillators II will discuss the role of the light-emitting compound in a double-solute scintillating system and present the characteristics of 24 such compounds

How to Control a Boiling Reactor

Dynamic control of boiling-water power reactors is complicated by changes in moderator density under various conditions. A servo analogy is useful for predicting trends

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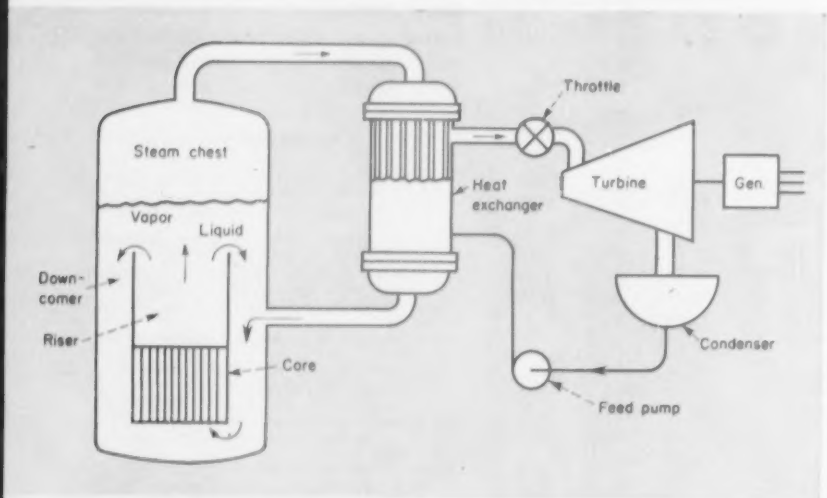

FIG. 1. Closed-cycle boiling reactor plant

BOILING REACTORS, pioneered by Argonne National Laboratory, have very attractive economical advantages. It has been proven by experiments (*1*) that a significant amount of power can be removed from such reactors. However, the fact that a boiling reactor is moderated by a two-phase mixture poses a much more complex control problem than encountered in a reactor having a single-phase moderator. It is the problem of dynamic control that represents probably the last important uncertainty of the boiling-reactor concept.

A closed-cycle boiling-reactor plant is shown in Fig. 1. The plant consists of a heterogeneous reactor moderated and cooled by water, a pressure vessel, an intermediate heat exchanger, and a turbo-electric load. Water from the downcomer flows up through the core, where vapor bubbles are generated. This two-phase mixture enters the riser, at the top of which the bubbles are disengaged. The separated steam flows to the steam chest while the liquid enters the downcomer to be recirculated through the core. Circulation through the reactor is promoted by the difference in coolant density around the recirculating loop (*2, 3*). The steam chest supplies wet steam to the intermediate heat exchanger, where secondary steam for the turbo-electric plant is generated.

Condensate in the primary steam loop is returned to the reactor by gravity while a feed pump is used in the secondary steam loop.

Moderator density coefficient of reactivity. The vapor fraction in the core of a boiling reactor is not constant; it varies from zero at the core entrance to a maximum value at the exit. In relating moderator density to reactivity, it is assumed that a spatial average of vapor fraction can be used. Figure 2 shows that for constant pressure the moderator density varies inversely with f_v. For constant f_v, ρ_{avg} varies inversely with pressure.*

Since the nuclear characteristics of the reactor depend on the physical properties of the moderator, the effective multiplication constant of the reactor will be a function of moderator density. An increase in moderator density can cause either an increase or decrease in reactivity depending on the core design. The change in reactivity per unit change of moderator density is defined as α, the moderator density coefficient of reactivity.

Constant Pressure Operation

If a boiling reactor were operated at constant pressure (e.g., in an open tank exposed to the atmosphere), reactivity would be a function of vapor fraction and moderator density coefficient of reactivity only. Such a reactor would be unconditionally self-regulating if α were positive. For example, assume a reactor were operating at point "a" on Fig. 2. An increase in power would cause f_v to increase and thus reduce ρ_{avg}. The decrease in ρ_{avg} would reduce reactivity and cause reactor power to decrease. While such a reactor would be self-regulating, large oscillations in power could occur. This condition will be discussed later.

Operation with Turbine Load

In an actual power plant, the reactor pressure could easily vary as a result of changes in turbine load. The pressure variations would be more sensitive to load changes if steam were supplied to the turbine directly from the reactor, rather than using an intermediate heat exchanger as shown in Fig. 1. Unfortunately, variations in turbine load will

* Note that for a given pressure and coolant velocity, f_v is directly proportional to reactor power.

at best produce intolerable excursions in reactor pressure. This can be demonstrated by assuming that the reactor is critical and operating at full power at point "a" on Fig. 2. Provided α is not zero and the effect of neutron temperature on reactivity is negligible, the steady-state average moderator density must be constant for all levels of reactor power. Therefore, for zero power demand, the reactor must shift from point "a" to a point where ρ_{avg} is the same but f_v is zero. Point "b" satisfies these conditions at the expense of tremendously increasing reactor pressure. Since it is desired to operate the reactor at constant pressure to keep the cost of the pressure vessel down, such a large pressure excursion would be intolerable.

Servo Analogy

The foregoing discussion suggests that a boiling reactor plant can be considered as a servomechanism in which one of the components in the forward loop (the reactor) is itself a closed-loop system.

Such a model is shown in Fig. 3. The transfer function $K_1(jw)$ represents the reactor core; $K_2(jw)$ represents the thermodynamic system, which includes the steam chest, recirculating loop, and the turbo-electric load. The transfer function $K_3(jw)$ relates feedback to the reactor resulting from differences in power output and power demand. It should be noted that this feedback manifests itself predominantly as parametric forcing of the reactor.* Because of this fact, analysis of the entire system shown on Fig. 3 by conventional methods of servomechanism design would at best be extremely difficult. However, the model shown is of some value in that it: (a) allows the designer to formulate some general principles concerning the over-all system; and (b) permits analysis of reactor stability for constant-pressure operation. This second point results from the fact that for constant-pressure operation the transfer function of the entire system reduces to the transfer function $K_1(jw)$. This transfer function is analyzed readily by known servomechanism design principles (4), as will now be shown.

The transfer function $K_1(jw)$ de-

* If this parametric forcing could be converted to an equivalent direct forcing, $K_3(jw)$ would represent a power coefficient of reactivity.

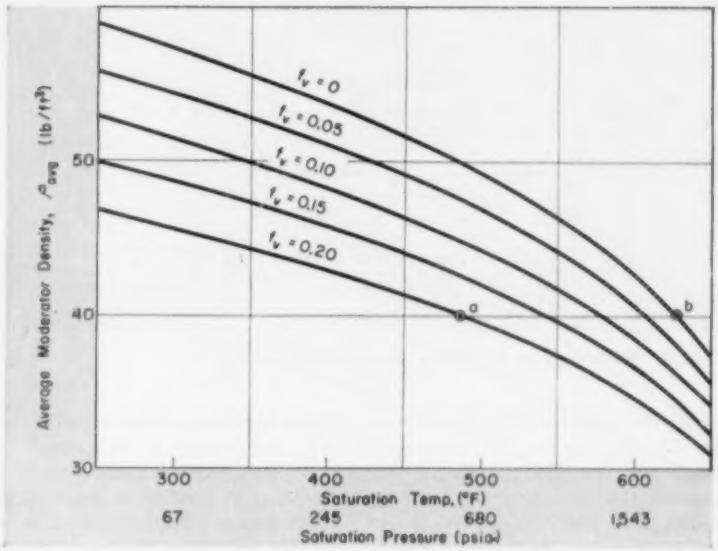

FIG. 2. Average moderator density vs. saturation temperature and pressure, with average vapor fraction as a parameter

SYMBOLS

A_f = area of core heat-transfer surface, ft²
C_f = heat capacity of fuel elements, Btu/°F
C_1, C_2 = constants
f_v = average vapor fraction in core, volume of steam per unit volume of moderator averaged over core volume
f_{v_o} = steady-state average vapor fraction
h = core heat-transfer coefficient, Btu/sec/ft²/°F
$j = \sqrt{-1}$
k = effective multiplication constant of reactor
k_s = spurious change in k
k_{f_b} = change in k caused by change in ρ_{avg}
K_v = open loop gain of $K_1(jw) = C_1 f_{v_o} \alpha_o (\rho_f - \rho_g)$
p = reactor pressure
p_o = reference pressure
P_d = power demanded by reactor plant load
P_o = power delivered to reactor plant load
P_r = power generated in reactor
P_{r_o} = steady-state reactor power
P_x = power removed from reactor core by vapor transport and delivered to steam chest
T_f = reactor fuel-element temperature, °F
T_s = moderator saturation temperature, °F
w = frequency, radians/sec
α = moderator density coefficient of reactivity, $\%k$/lb/ft³
α_o = moderator density coefficient at vapor fraction f_{v_o}
β = delayed neutron fraction
γ = power coefficient of reactivity
γ_o = power coefficient at reactor power P_{r_o}
δ = denotes small variation about equilibrium value
ξ = change in moderator density per unit change of reactor power
λ = effective decay constant of delayed neutrons, sec⁻¹
ρ_{avg} = moderator density averaged over core volume, lb/ft³
ρ_f = density of moderator liquid phase, lb/ft³
ρ_g = density of moderator vapor phase, lb/ft³
τ = time constant, sec
τ_c = coolant transit time through core, sec
l^* = neutron lifetime, sec
$\tau_1 = 1/\lambda$
$\tau_2 = l^*/\beta$
$\tau_3 = C_f/A_f h$
$\tau_4 = C_2 \tau_c$

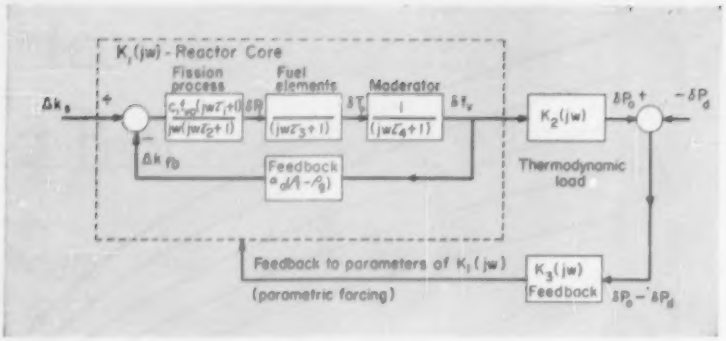

FIG. 3. Block diagram for boiling reactor plant

scribes the behavior of the fission process, the fuel elements, and the reactor moderator. In deriving $K_1(jw)$, the pressure, the coolant velocity, and the fuel-element heat-transfer coefficient are assumed constant. The kinetic equations of the reactor are linearized, implying that study must be limited to small perturbations of reactivity and reactor power about some steady-state condition (*5*). In addition, one group of delayed neutrons is assumed rather than six.

The open loop gain of $K_1(jw)$ is a function of the steady-state vapor fraction f_{v_0}, the moderator density coefficient at the operating condition α_0, and the difference in density between the liquid and vapor phases of the moderator, $(\rho_f - \rho_g)$.

The phase relationship of $K_1(jw)$ is determined by the time constants τ_1 through τ_4. The time constants τ_1 and τ_2 are functions of the nuclear characteristics of the reactor, while τ_3 is a function of C_f, A_f, and h. The time constant τ_4 is related to the coolant transit time through the core. An examination of the open loop transfer function shows that at high frequencies the phase shift approaches 270 deg. Therefore, a high loop gain will result in an oscillatory system.

According to this model, the maximum permissible vapor fraction is determined by the operating pressure, the moderator density coefficient α_0 and the time constants τ_1 through τ_4. Therefore, operation at higher pressures is attractive in that larger values of f_{v_0} can be tolerated since the density difference of the two phases $(\rho_f - \rho_g)$ is smaller (assuming of course the same time constants and constant α_0). However, increasing the pressure does affect the time constants τ_3 and τ_4 and usually α_0 as well, so that the relationship between the maximum permissible value of f_{v_0} and pressure is not a simple one.

By changing the parameters of the model, it is possible to establish stability trends. Furthermore, it is reasonable to assume that such stability trends of the model will be representative of the trends in the actual nonlinear system. For example, if the system represented by $K_1(jw)$ is made more oscillatory, one would expect the physical system to become more oscillatory. If this hypothesis can be proven, then the above model provides means for correlating the permissible values of system parameters at different operating conditions. Correlation is accomplished by assuming some arbitrary criteria for stable operation. In this respect, the model predicts the variation of permissible vapor fraction with pressure observed in the early Borax experiments (*6*).

Additional work is required before this model can be used to determine absolute system stability (i.e., do more than predict trends). Specifically, the nonlinearities of the system and the dependence of coolant velocity on coolant density must be incorporated. Furthermore, more experimental evidence is required to substantiate the above hypothesis since there is still much unknown about the basic phenomenon of boiling.

Power Coefficient of Reactivity

In the discussion of Fig. 2, it was pointed out that for a reactor having a finite value of α, changes in load demand will cause variations in operating pressure. Whether or not these pressure excursions are bounded, and if so to what degree, will be influenced by the size of real and effective heat capacities in the system and the power coefficient of reactivity.

The sizes of real and effective heat capacities determine in large measure the response time of the over-all system. Large heat capacities introduce significant lags, thereby increasing system response time. An example of an effective heat capacity is the steam chest above the reactor core. If the volume of this were increased infinitely, the response time of the change in reactor pressure to changes in throttle setting would become infinite. The volume of secondary steam in the intermediate heat exchanger is another example of an effective heat capacity.

Perhaps γ, the power coefficient of reactivity, is the most important factor affecting the response of the over-all system to changes in power demand. It can be defined as

$$\gamma_0 = P_r \left.\frac{dk}{dP_r}\right|_{P_r = P_{r_0}} \qquad (1)$$

The power coefficient of reactivity is a measure of the rate of change of reactivity with respect to reactor power. This factor is in turn influenced by operating pressure, vapor fraction, and type of circulation. A necessary condition for the system to be stable is that γ must be less than zero. Equation 1 can be rewritten to include

$$\gamma_0 = P_r \frac{\partial k}{\partial \rho_{avg}} \cdot \frac{d\rho_{avg}}{dP_r} = P_r \alpha \frac{d\rho_{avg}}{dP_r} = P_r \alpha \xi \Big|_{P_r = P_{r_0}} \qquad (2)$$

This equation shows that γ is proportional to α and ξ. If α is assumed to be positive, then ξ must be negative for the system to be stable. As mentioned earlier, α is a function of the nuclear properties of the reactor.

The function ξ depends on operating pressure, vapor fraction, and type of circulation. This can be seen from Fig. 4, which is the same as Fig. 2 except that steady-state power-removal curves for a particular reactor design are superimposed. These curves are typical for a system employing natural circulation. For a system employing forced circulation, the P_s curves will depend on how the recirculating pump is programmed. For constant pump speed, the P_s curves will be similar to those shown on Fig. 4.

It can be shown that the function ξ will be negative at any operating point where

$$(d\rho_{avg}/dT_s) < 0 \qquad (3)$$

for constant P_s.

Thus, Eq. 3 defines the region of negative power coefficient of reactivity for positive values of α. The boundary between the regions of positive and negative values of ξ is shown on Fig. 4.

Several facts are evident: (a) if α is positive, the system will eventually reach a point where $\gamma < 0$ even if initially $\gamma > 0$ as at point "a" on Fig. 4; (b) for positive α, system stability is promoted by operating at higher pressures and lower vapor fractions.

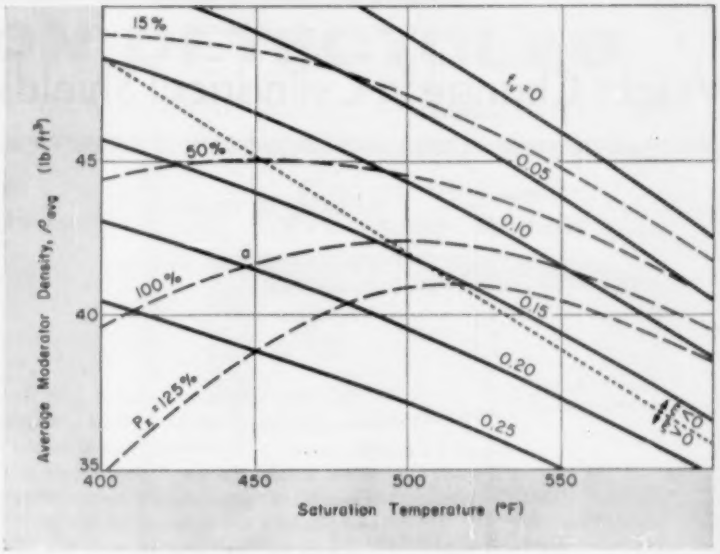

FIG. 4. Curves for determining power coefficient of reactivity

Basic Control Schemes

Three basic schemes for controlling a boiling-reactor power plant are shown on Fig. 5. Since it is difficult to obtain both wide range and fast response in a single control element, a physical system would probably use some combination of two of these schemes. It must be emphasized that these represent basic control concepts and do not include any necessary anticipatory loops, etc.

Scheme 1. As shown on Fig. 5, the reactor load is maintained constant by a steam dumping transition in parallel with the turbine. The flow through the steam dump is controlled by a pressure error signal such that a decrease in turbine load increases steam flow through the dumping transition. In this manner, reactor load is always constant. This scheme would be very attractive if it were not for the fact that it is very uneconomical at low power demands, since large amounts of power are thrown away.

Scheme 2. This scheme provides for compensating reactivity changes, due to moderator density changes, by moving control rods. The rods are programmed by a pressure error signal so as to increase reactivity in response to a decrease in reactor pressure. This method *may have* the disadvantage that large changes in reactivity will have to be made in comparatively short intervals. For this reason, it is felt that this scheme is not as inherently safe. Of course, just *how fast* a control system is needed depends on the size of heat capacities, power output, etc., of the particular design.

Scheme 3. Here vapor fraction is maintained constant for all power levels through the use of forced circulation. The recirculating pump speed is controlled by the pressure error signal in a manner such that pump speed varies inversely with reactor pressure. In addition to economical considerations (cost of pump and pumping power) this approach has the same disadvantages as Scheme 2. However, this scheme would allow a greater amount of power to be removed from a given core. Therefore, it would seem prudent to at least make provisions for it in any boiling reactor contemplated at this time.

As an example of how the above schemes can be incorporated into a control system, consider Schemes 1 and 2. A system can be designed in which fine control is provided by adjusting the flow rate through a steam dump (Scheme 1). When the limit of the steam dump control is reached, the reactor control rods are used for shimming (Scheme 2). Thus a small amount of steam will be dumped at all power levels. This control system would incorporate the safety of steam dump control with the economy of control-rod regulation.

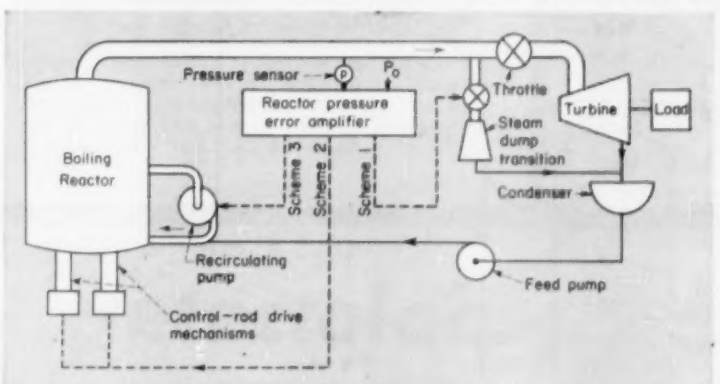

FIG. 5. Basic control schemes for a boiling reactor

* * *

The author wishes to thank F. Holzer for his many helpful suggestions made during the preparation of this paper. Some of the material (notably Figure 4) was originated by the author as part of a group thesis at the Oak Ridge School of Reactor Technology.

This article is adapted from a paper presented at second national annual meeting of the IRE Professional Group on Nuclear Science, September 15, 1955, in Oak Ridge, Tennessee.

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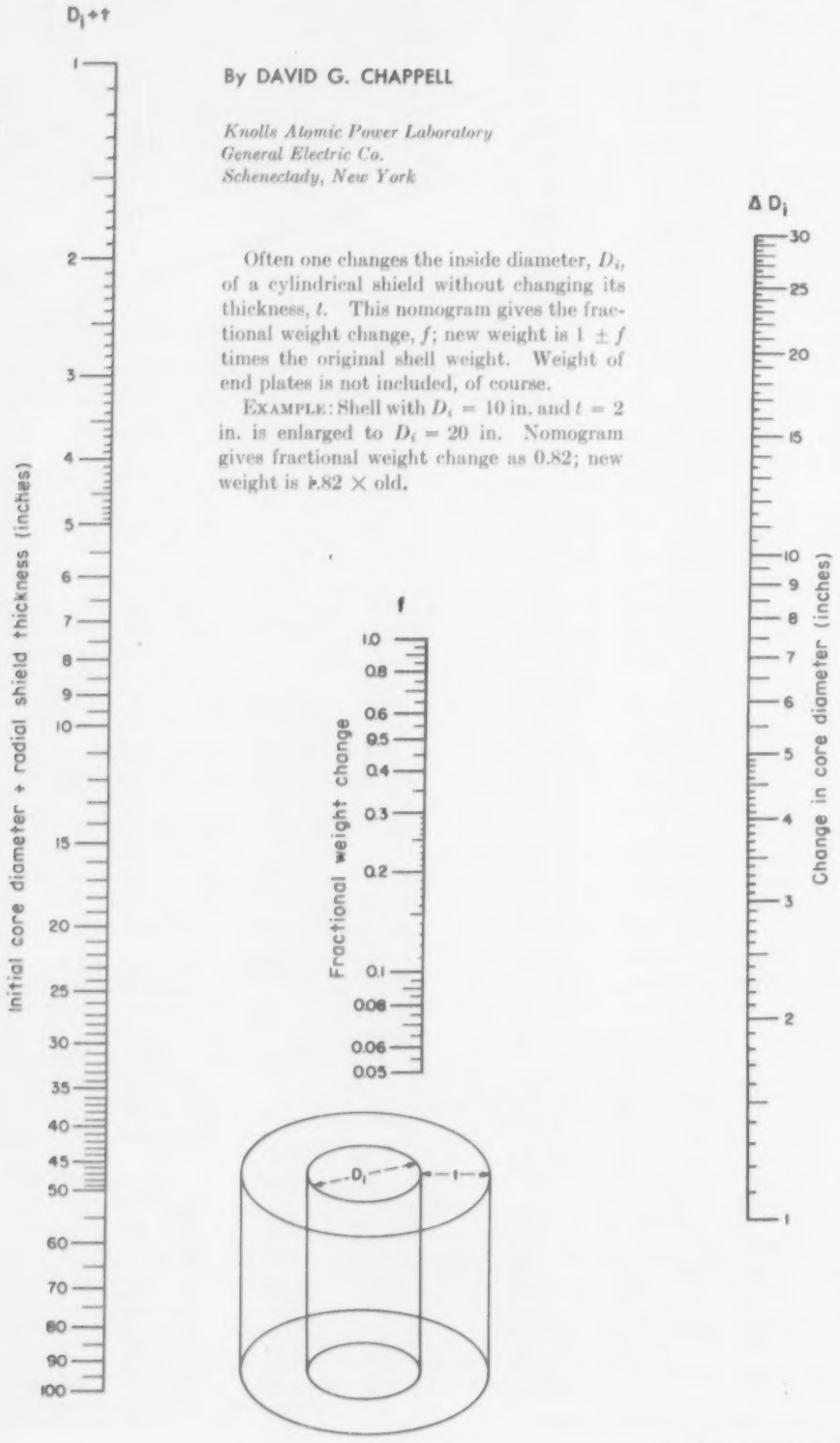
Weight Change in Cylindrical Shields

By DAVID G. CHAPPELL

Knolls Atomic Power Laboratory
General Electric Co.
Schenectady, New York

Often one changes the inside diameter, D_i, of a cylindrical shield without changing its thickness, t. This nomogram gives the fractional weight change, f; new weight is $1 \pm f$ times the original shell weight. Weight of end plates is not included, of course.

EXAMPLE: Shell with $D_i = 10$ in. and $t = 2$ in. is enlarged to $D_i = 20$ in. Nomogram gives fractional weight change as 0.82; new weight is 1.82 × old.



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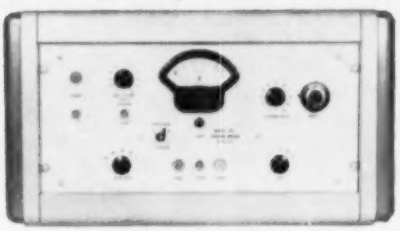

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This instrument, with the DP21 Scintillation Probe, is ideal for scanning brain tumors or doing thyroid uptake work. It selects primary ionizing radiation to the exclusion of secondary and background radiation, resolving energies as close as 44 kev., such as Iodine and Chromium. The precision of the spectrometer and its sharp counting rate differential greatly increase the speed and accuracy of measurements.

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Simple Fall-Out Meter Uses CdS

By C. C. KLICK, H. J. PEAKE, P. T. COLE, H. RABIN, and J. J. LAMBE
U. S. Naval Research Laboratory
Washington, D. C.

The dose-rate meter described here was designed to survey the gamma radiation of widely dispersed radioactive dust from a nuclear explosion. It is sensitive over the range 0.1–1,000 r/hr and uses only commercially available components.

The detector is a cadmium sulfide crystal. Frerichs (*1*) has investigated the CdS γ-ray response, and Jacobs (*2*) has adapted it to X-ray detection in commercial equipment.

The crystal is in series with a battery and a current-measuring device consisting of a capacitor shunted by a neon lamp (Fig. 1). Under gamma irradiation, the crystal passes current, charging the capacitor to the neon tube firing point. The lamp flash rate indicates the γ-ray intensity. A model of this meter has been constructed (Fig. 2). Calibration results are given in Fig. 3.

To reduce the enhanced response for soft γ-rays, characteristic of high-atomic-number detectors, the crystal is surrounded with 0.035-in.-thick lead sheet. A square lattice of 0.013-in.-diameter holes is drilled in the sheet with $\frac{1}{16}$ in. between centers.

Energy dependence was checked with unfiltered 100- and 200-kv X-rays and Co^{60} γ-rays. The relative response was 0.9, 1.2, and 0.9, respectively.

Several improvements might extend the range of the detector down to 0.01 r/hr. (1) The voltage applied to the crystal might be increased. Since the firing and extinguishing voltages of the neon lamp are approximately 75 and 60 volts, the average voltage applied to the CdS crystal is 67 volts for a 135-volt battery. Increasing the applied voltage to 180 volts should almost double the response. (2) Since the crystal used is a thin flake, greater volume would give better sensitivity. (3) Electrode spacing should be a minimum. (4) Crystal selection may be worthwhile; 10 crystals investigated showed a 10-to-1 response variation. (5) Capacitor can be reduced; the limitation is that lamp-discharge intensity decreases with capacitor size until it becomes difficult to view.

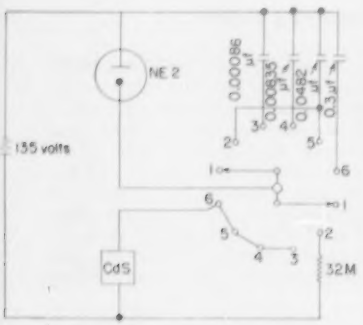

FIG. 1. Meter circuit. Flash rate of 1/sec indicates dose rate of 1 r/hr in switch position 3, 10 r/hr in position 4, 100 r/hr in position 5, and 1,000 r/hr in position 6; in position 3, 1 flash in 10 sec indicates 0.1 r/hr. Position 2 substitutes resistor for crystal and gives 1/sec flash rate for battery in good condition. Position 1 is "off." Life of battery should be shelf life

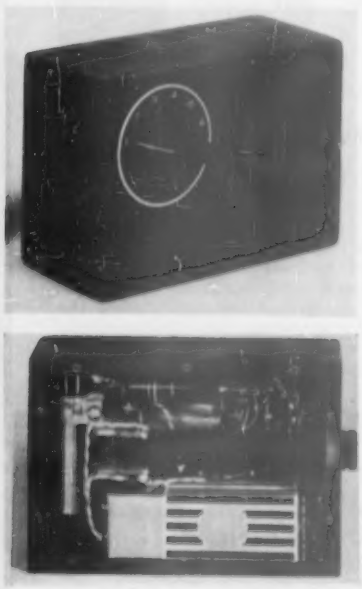

FIG. 2. Exterior and interior of meter

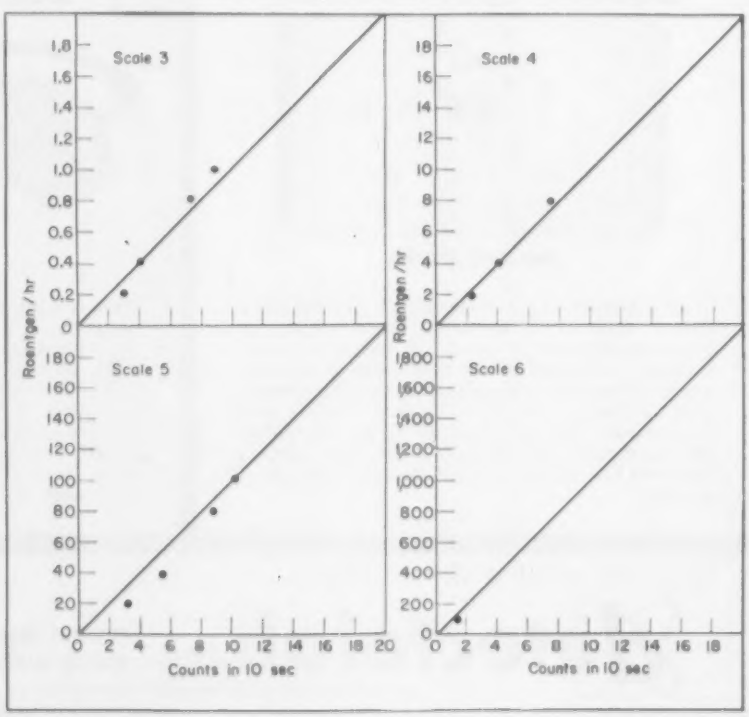

FIG. 3. Meter calibration at 0.2–100 r/hr. Straight lines give nominal range values

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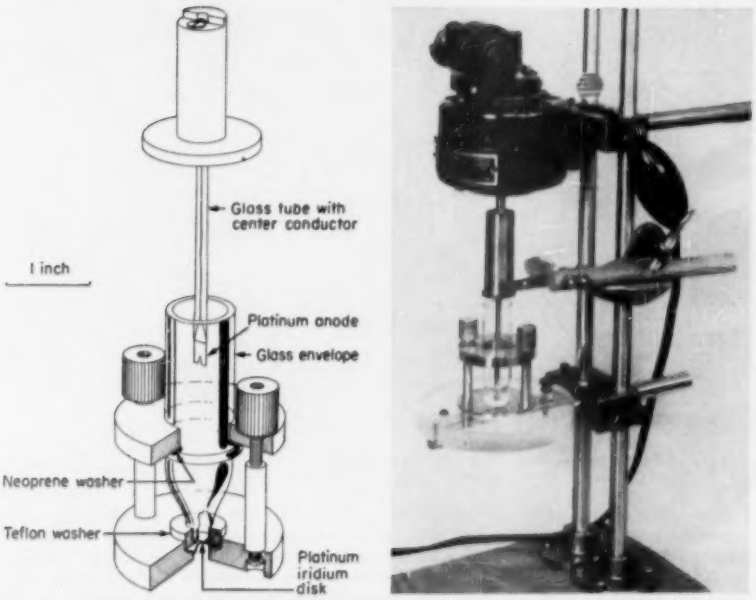

FIG. 1. Rotating-anode electrolytic cell. Deposition area is defined by Teflon washer. Anode stirring action must be vigorous for uniform cobalt distribution. Platinum anode is accurately positioned 0.5 mm above disk. Cell can be removed or replaced quickly and accurately by lowering or raising Lucite plate

Secondary-Standard Co^{60} Sources Prepared by Electrodeposition

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The cobalt-60 gamma-ray sources to be described were developed as secondary standard sources in the millicurie range. The four sources, 0.055–55.0 millicuries of cobalt-60, were prepared by quantitatively electrodepositing cobalt metal and encapsulating it in platinum by vacuum brazing. This design avoids the poor geometry, high self-absorption, and, in the usual glass container, the fragility of solution sources, as well as the nonuniform distribution and sometimes high self-absorption of evaporated solution sources.

The sources have been calibrated relative to ampoules (1.0 and 0.1 rutherfords, ~5 ml) of cobalt chloride solution available from the National Bureau of Standards. The resultant absolute accuracy is about the same as the absolute accuracy of the NBS sources.

Electrodeposition

The source preparation is a modification of a method described by Scott* for quantitatively determining cobalt by electrolysis, using a cobalt chloride amino complex as electrolyte. The modifications provide maximum speed and completeness of cobalt deposition, maintain a good-quality deposit, and allow a small volume of electrolyte.

The cobalt-60 was obtained from the Oak Ridge National Laboratory as a slightly acid cobalt chloride solution. The proportions of the components adopted for the electrolyte were: ORNL cobalt chloride solution to give 21.3 mg cobalt metal; distilled water to give a final volume of 7.3 ml; ammonium peroxydisulphate, 340 mg; ammonium hydroxide (specific gravity 0.90), 0.8 ml. For a neutral cobalt chloride solution, use 0.5 ml, since about 0.3 ml was necessary to neutralize the acidity of the ORNL cobalt chloride solution.

To prepare the electrolyte, dilute the cobalt chloride solution to about 6.5 ml with distilled water; add ammonium peroxydisulphate; and reflux the solution for about 45 min. Complex formation begins during this stage, and when boiling is completed should give a clear pink solution. When the solution has cooled, the ammonium hydroxide should be very slowly added and the solution allowed to stand for about 24 hr for complex formation, giving a dark-brown-red solution.

The activity of this "stock" solution is about 10 mc/ml so that it can be used undiluted to prepare the most active of the four sources. The three smaller sources are prepared by diluting the stock solution with an identical solution of stable cobalt. Thus, the latter has lower specific activities, but the total amount of cobalt per milliliter is unchanged. This allows identical deposition procedures for each source with identical self-absorption.

The cobalt is deposited by means of a rotating-anode electrolytic cell (Fig. 1). The deposit is about 0.0035 in. thick and covers an area 0.250 in. in diameter in the center of a platinum-10% iridium disk, $\frac{5}{8}$ in. diameter by 0.010 in. thick.

If the deposition is begun at a relatively high current, and the current re-

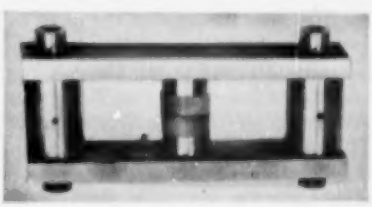

FIG. 2. Jig, for holding source during brazing, is made of type 304 stainless steel; source is clamped between two lava blocks to separate it from steel. One-eighth-inch solder joint has proved extremely strong

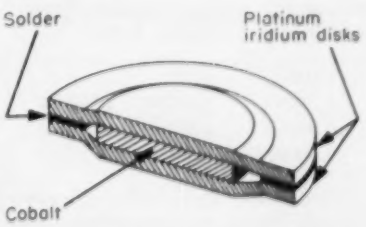

FIG. 3. Assembled source cross section

* Wilfred W. Scott, "Scott's Standard Methods of Chemical Analysis," 5th ed., Vol. 1, p. 315, N. H. Furman, edit. (D. Van Nostrand Co., New York).

duced at intervals during the deposition, a tightly adherent surface may be obtained in a reasonable time. The schedule adopted was 12 hr at 8 ma, 6 hr at 4 ma, and 24 hr at 2 ma.

The cobalt complex used here is rather sensitive to the ammonium hydroxide content of the solution. An excess promotes the formation of an insoluble crystalline precipitate when the solution is stored for more than a few days. For this reason the ammonia content of the solution has been adjusted such that the complex will be completely formed, but the solution will remain useable for several weeks. However, during the electro-deposition, the electrolyte must be strongly ammoniacal, to prevent the formation of deposits on the anode. About 0.5 ml of ammonium hydroxide per 5 ml of solution should be added just before deposition is begun, and at 8–12 hr intervals thereafter, to replace that decomposed during the electrolysis.

Encapsulation

The cobalt is sandwiched between the disk on which it was deposited and a similar disk that had been lightly engraved to show the nature and activity of the source. The disks are then brazed together around the edge with copper-silver-eutectic solder. The brazing is done in a vacuum furnace at 800° C to eliminate the need for a flux. During the brazing, the sources are held in the jig shown in Fig. 2. The solder, also sandwiched between the disks, is an annulus 0.002 in. thick, extending from the edge of the disks to within $\frac{1}{16}$ in. of the cobalt. A 0.002-in. tangential slit is cut through the annulus to ensure rapid and complete evacuation of the assembly interior. This slit is completely obliterated when the solder flows. A diagram of a source is shown in Fig. 3.

Calibrating Sources

The scheme for preparing the source electrolyte solutions from the stock solution is shown in Fig. 4.

Assuming complete depletion of the cobalt from the electrolyte, the activities of the resultant electrodeposited sources were calculated to be

1.000	± 0.000	
0.09953	± 0.00003	(0.03%)
0.00999	± 0.000002	(0.02%)
0.0009945	± 0.0000003	(0.03%)

relative to the largest source after corrections for pipette calibrations. The relative activities of these sources were

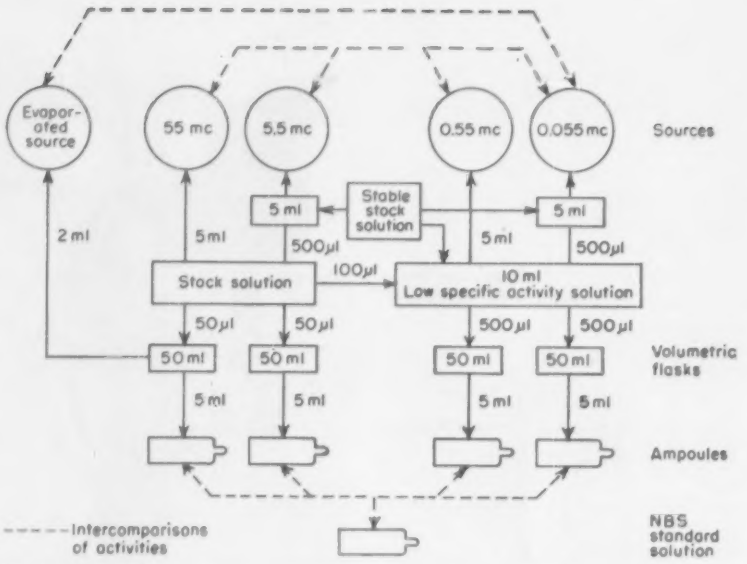

FIG. 4. Dilution and calibration procedures. Electrolyte for 55-mc source obtained by pipetting 5 ml of stock solution into cell. For 5.5-mc source, 500-µl of stock solution are pipetted into cell and diluted to 5 ml with pipette rinse and inactive cobalt complex. For 0.55- and 0.055-mc sources, 100 µl of stock solution are diluted to 10 ml with pipette rinse and inactive cobalt complex; two source electrolytes are then obtained from this low-specific-activity solution in same way larger sources were obtained from stock solution

measured with a Victoreen thimble chamber and a charger null-reader device as

1.000	± 0.00057	(0.057%)
0.0997	± 0.00014	(0.14%)
0.00995	± 0.000013	(0.13%)
0.000994	± 0.0000024	(0.24%)

relative to the largest source.

The activity remaining in solution, on the cell walls, stirrer, etc., was measured to be about 0.14% of the total source activity for the three largest sources. The activity left after depositing the smallest source was too small to measure with satisfactory accuracy and was assumed to be the same percentage as the others.

To obtain a calibration of these sources relative to the NBS standard, a 50-µl sample of the stock solution was pipetted before and after the extractions for the two largest sources were made, acidified and diluted to 50 ml. Two 5-ml samples from each of these flasks were pipetted and sealed in 5-ml ampoules of the same dimensions as NBS standard-source ampoules. A 500-µl sample of the low-specific-activity solution was pipetted before and after extractions for the two smallest sources were made and each of these was acidified and diluted to 50 ml. Two 5-ml ampoules were obtained from each of these.

These eight ampoules and two NBS standards were exposed individually to a 4π gamma ionization chamber measured by a Victoreen charger null-reader device. The ratio of the readings obtained from the eight unknown ampoules to NBS standard ampoules gave the specific activity of the two solutions from which the four sources were constructed. The ampoule readings agreed with one another within a probable error of ±0.33%. The two standard ampoules agreed with one another within a probable error of ±0.25%. Thus, the four electrodeposited sources were calculated to be

54.86	± 0.22	mc
5.460	± 0.022	mc
0.5482	± 0.0022	mc
0.05456	± 0.00022	mc

as of June 1, 1955.

These values are known to within 0.4% probable error relative to the standards. The absolute value of the standards are certified to ±2% as of October 1, 1953. All values were corrected to June 1, 1955, using 5.2 yr for the Co^{60} half-life. The absolute accuracy of these sources is then ±2%.

A final check was made to provide a more direct comparison between the electroplated sources and the solutions. A 2-ml sample was taken from one of the 50-ml volumetric flasks containing the 50 µl of stock solution. This was deposited and evaporated on a platinum

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disk identical with those used for plating. The deposit was then covered with another platinum disk and compared with the smallest of the electrodeposited sources. This comparison was made with a G-M tube. The ratio of activities measured was within 0.3% of that calculated and falls well within the error of this particular measurement.

Conclusions

This method of preparing cobalt sources provides a very adherent uniform deposit of accurately controlled dimensions. No cracking or flaking of the deposit or separation of the deposit from the platinum disk was observed upon flexing the disk. The assembled source is extremely rugged and should remain hermetically sealed indefinitely unless deformed enough to rupture one of the disks.

The characteristics of the deposit suggest the application of this method to the preparation of cobalt-60 beta sources, and perhaps to other beta emitters, by omitting the covering platinum disk. A direct extrapolation of the activity losses in electrodeposition gives a 1.4% loss from a 0.5-ml electrolyte and a cobalt deposit of 0.55 mg/cm². Larger losses than 1.4% could be determined accurately in fairly active sources, permitting even thinner deposits.

Although in this case the sources were prepared to be only in an approximate activity range, standardization of the specific activity of the electrolyte prior to the deposition of the sources would allow sources of an exact activity to be prepared.

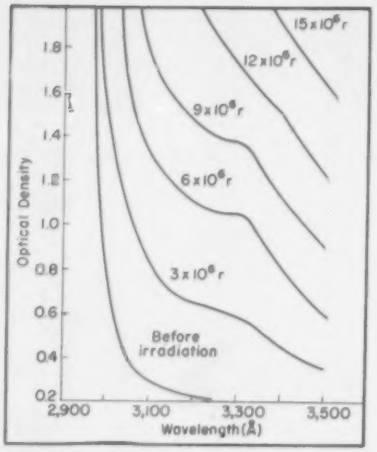

FIG. 1. Optical absorption spectra of polystyrene; u-v absorption edge moves towards longer wavelengths with increasing dose

High-Dose Measurement by Optical Absorption

By J. F. FOWLER and M. J. DAY
Radiotherapy Department
Royal Victoria Infirmary
Newcastle, England

The change produced in the optical absorption of various substances has been suggested as a means of measuring high doses of ionizing radiation. The darkening of red-dyed polymethyl methacrylate (Perspex 400) was found to be linear with X-ray dosage up to 3×10^5 roentgens (*1*). Silver-activated glass was recently suggested for measuring gamma and beta doses between 10^3 and 10^6 rep (*2*). A saturation of absorption with increasing dosage was found above about 2×10^6 rep.

It is our purpose to put forward a system whereby doses of 10^6–10^9 or higher can conveniently be measured. It is suggested that the clear plastics polymethyl methacrylate (PMMA) and (preferably) polystyrene may be useful.

Spectral Characteristics

These plastics show no pronounced absorption bands in the visible spectrum, but each has a "u-v cut-off" at about 2,800 Å. Upon irradiation, this u-v edge moves up into the visible region, producing the characteristic brown discoloration also observed in some glasses (Fig. 1).

Polystyrene shows in addition a small absorption band at 3,300 Å due to irradiation. This small band is obscured by the u-v edge, as it moves up into the visible region, at doses above about 2×10^7 r. No such peak has been observed in the spectrum of irradiated PMMA.

It is therefore suggested that absorption measurements should not be made at a wavelength corresponding to the peak of this or any absorption band. Figure 2 shows that absorption is linear with dose over a considerable range of wavelength, and indeed the smooth spectrum provides a convenient choice of sensitivities for such measurements, increasing towards the u-v.

Dosage Dependence

The increase of optical absorption with dose for PMMA and polystyrene is linear up to about 2×10^7 r (Fig. 2). PMMA is slightly more sensitive than polystyrene up to this dose.

As the dose is further increased, PMMA shows a gradual saturation beginning before 10^8 r is attained (Fig. 3). Above this dose, molecular degradation is important, and specimens of PMMA become too brittle for practical use.

Polystyrene, on the other hand, shows a "knee" in the curve at about 2×10^7 r. After this the curve continues to rise linearly with a reduced slope, this slope being adequate for dose determination. It is possible that the

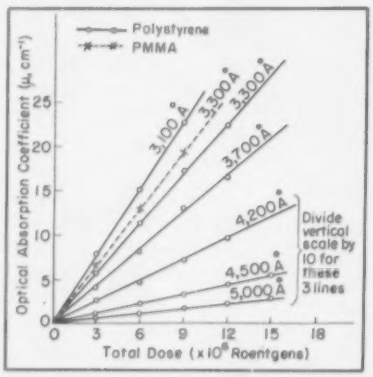

FIG. 2. Linearity of induced optical absorption with total dose

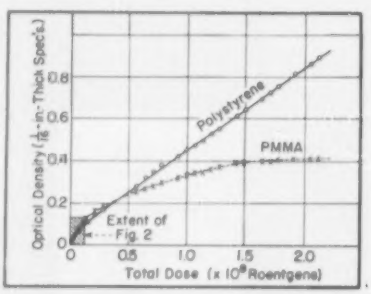

FIG. 3. Induced optical absorption vs total dose at higher doses

"knee" is associated with the disappearance of the small band shown in Fig. 1. No saturation was observed up to the highest dose administered, 2×10^8 r. Polystyrene undergoes no serious deterioration of mechanical properties at this dose level.

Induced-Absorption Decay

The new absorption bands produced by the radiation decay slowly in the

period following irradiation. As noted by Day and Stein (*1*) with smaller doses of radiation, the decay is partially due to diffusion of oxygen into the specimen, and there is also a thermal decay. Since both these processes are activated, their relative magnitude depends markedly upon temperature.

In PMMA at room temperature, the oxygen effect produces, after a week or so, complete bleaching in an increasing superficial layer with a sharp line of demarcation from the unbleached region. This suggests that oxygen reacts virtually instantaneously with the absorption centers, the rate of this process being governed by oxygen diffusion. In polystyrene the thermal bleaching process appears to predominate at first, the absorption coefficient initially falling to half its value in 4 days, the decay thereafter taking place at the much slower rate of a few per cent per week.* In practice, if absorption measurements are made within a few hours after the end of irradiation these effects (at room temperature) are not important.

No appreciable optical bleaching has been observed.

Experimental Technique

The curves of Figs. 1 and 2 were obtained using 220-kvp X-rays at about 4,000 r/min. The optical measurements were made on a Unicam spectrophotometer.

The curves of Fig. 3 were obtained using Co^{60} γ-rays at about 5,000 r/min. The longest irradiation was 30 days. A simple double-beam photometer was used for measuring these specimens, together with an Ilford Filter No. 600 (transmission 3,900–4,500 Å, with peak about 4,200 Å). The specimens were cut from commercial material $\frac{1}{16}$-in. thick.

The results obtained with the Co^{60} γ-rays (1.33 Mev) and 220-kvp X-rays exclude any major energy dependence.

* * *

The authors wish to record their thanks to Dr. F. T. Farmer, Head Physicist of this department, for helpful suggestions and encouragement; Dr. Freda Herbert and Dr. Smith, of the Biochemistry Dept., Royal Victoria Infirmary, for the use of the Unicam spectrophotometer; and to Dr. J. Weiss and Dr. A. Johnson, of King's College, Chemistry Dept., Newcastle, for the use of the Co^{60} source.

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1. M. J. Day, G. Stein, *Nature* **168,** 644 (1951)
2. J. H. Schulman, C. C. Klick, H. Rabin, NUCLEONICS **13,** No. 2, 30 (1955)

* After 6 months, no edge effect (due to oxygen diffusion) has been observed in polystyrene.

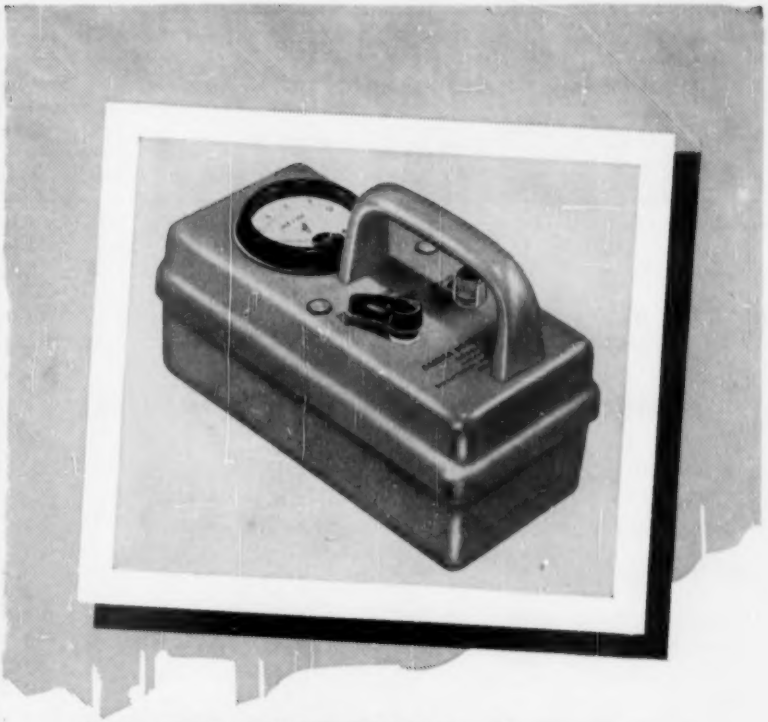

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TABLE 1—Calibration of X-Ray Films Using Kodalith Positive

Film	Particle diameter (μ)	Activity of particles* (dpm)	Spot diameter (mm) Exposure time 1 hr	2 hr	3 hr	16 hr	17 hr	26 hr	72 hr	5 days
Kodak Blue Line	250	68,250	2.0	3.0	3.15	8.0		8.75		
	†	5,170	0.5	0.65	0.9	2.9		3.0		
	200	22,300	1.1	1.35	1.85	4.8		5.0		
Kodak Type-K	250	66,582	2.1	2.6	3.2		5.1		8.3	
	175	7,775	0.8	0.9	1.1		2.0		3.3	
	†	4,840	0.6	0.8						
	200	21,164	1.2	1.4	1.8		3.2		5.2	
	250	5,974	0.8	0.9	1.0		1.9		3.1	
	225	16,380	1.1	1.3	1.8		3.1		5.2	
	200	13,979	1.0	1.1	1.7		3.0		4.7	
	†	21,878	1.2	1.5						
	300	12,209	1.0	1.2	1.6		2.9		4.9	
	50	3,890	0.5	0.7	0.9		1.5		2.9	
Ansco High Speed	250	66,582	1.5		2.0	6.1				11.5
	175	7,775	0.5		0.8	2.2				6.0
	250	5,974	0.3		0.5	2.0				5.4
	225	16,380	0.8		1.0	3.9				8.2
	300	12,209				3.0				7.0
	50	3,890	0.2			1.8				4.1

* All activities were compared to a Sr^{90}-Y^{90} standard with a counting efficiency of 42.6%.
† No particle size measurements were obtained.

How to Measure Beta Activity of Fission Particles Using Film

By CLARENCE SKILLERN
University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

This article describes a radioautographic method of using X-ray and photographic films to measure the beta activity of particles containing fission products. The method is limited to samples where activity originates from an isolated point source. Only particles of 50–300 μ diameter have been investigated. If a larger particle is used, the particle size and activity may affect the resulting spot size, and the calculations given here do not apply.

A large number of radioautographs were taken of settling trays containing fall-out fission-product particles. It seemed reasonable that a method could be devised for finding the activity of a particle by measuring the spot diameter. However, the periphery of these images appearing on the X-ray film was not clearly defined; hence, accurate measurements could not be obtained. It was suggested by members of the Health and Safety Laboratory, AEC New York Operations Office, that a Kodalith negative be made of the X-ray film spots. This was tried and a clear, reproducible outline was obtained (Fig. 1).

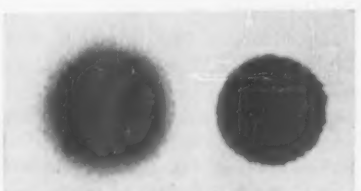


FIG. 1. Enlargements (approx. 10X) of spots obtained from radioautograph (left) and Kodalith print of radioautograph

Experimental

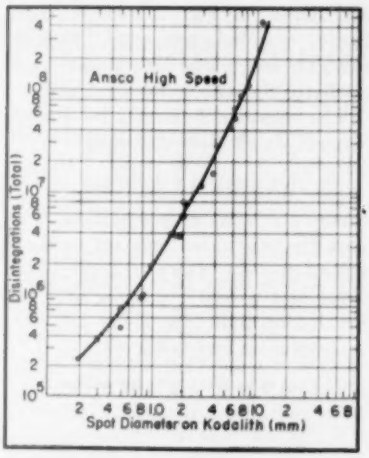
Several particles were obtained that had high beta-disintegration rates of fission products although the activity had decayed for several months. These were mounted on glass slides by spray-painting with Krylon plastic.

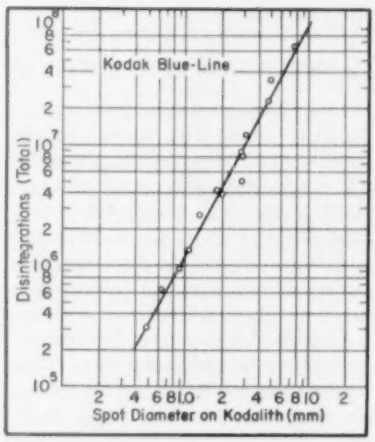
The samples were counted in a proportional counter and compared to a Sr^{90}-Y^{90} standard previously calibrated on a 4π system. The standards had similar backing and geometry.

The particles were then exposed to X-ray films, and by varying the exposure times and by using particles of different activities, various spot sizes were obtained. The diameters measured on the Kodalith prints are listed in Table 1. Two particles of different

TABLE 2—Spot Size on Kodak Type-K Film from 6-Day-Old Fission Products

Particle activity (dpm)	5-min exposure Diameter (mm)	Total disintegrations	10-min exposure Diameter (mm)	Total disintegrations
78,000	0.3	Unreadable	0.8	6.0×10^5
110,000	0.7	5.0×10^5	1.2	1.5×10^6
235,000	0.9	1.0×10^6	1.6	1.6×10^6





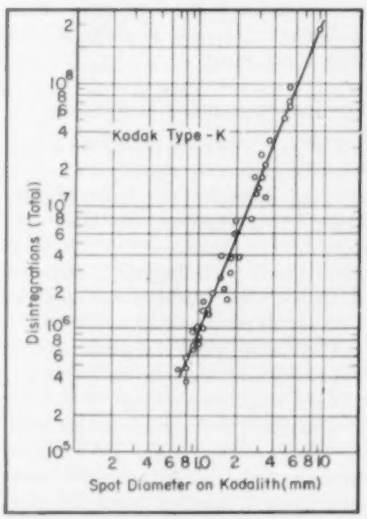


FIG. 2. Spot size on Kodalith film as function of beta activity, using three types of film for radioautographs

activities were also exposed for such times as to obtain the same total number of disintegrations; these spots were of the same size.

Results for three types of X-ray film

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are shown in Fig. 2. Ansco High Speed deviated somewhat from a straight line. The line slopes vary qualitatively with emulsion speed.

The equation of the line for Kodak Type-K X-ray film is given by

$$\log d = \log a + b \log s$$

where d = total disintegrations, s = spot diameter, a = intercept on the d axis where $s = 1$, and b = slope of line. Thus $\log d = 6.03 + 2.63 \log s$.
For Kodak Blue Line X-ray film, the corresponding expression is

$$\log d = 6.07 + 1.92 \log s$$

For Ansco High Speed film

$$\log d = \log a + B \log s + C (\log s)^2$$

Putting in pairs of values of d and s

$$\log d = 6.25 + 1.67 \log s + 0.48 (\log s)^2$$

The changing beta spectrum of gross fission products with time does not seem to affect the spot size significantly. The experiment was repeated with particles containing six-day-old fission products and gave points that fall within the limits of the previously prepared calibration curve for older fission products (Table 2 and Fig. 2, bottom).

Considerable care must be exercised in applying this technique to particles on filter paper or other material where the particle is embedded in the material. If the particle is not brought into real contact with the film, an unknown geometry factor enters, giving a spot that is too small.

Radioautographic Technique

The X-ray film was placed in contact with the particles in an exposure holder, then taped between two pieces of plate glass. After exposure, the films were developed in Ansco Liquidol Developer at 20 ± 0.5° C for 3½ min, transferred to Kodak X-ray liquid fix and hardener bath for 10 min, washed and dried.

The Kodalith film was placed next to the X-ray film in a printing frame and exposed to a 100-watt light at 8 ft for 5 sec and then developed in the Kodalith Developer at 20 ± 0.5° C for 3 min, or until the film displayed complete blackness under a Wratten Series OA filter 6 ft away. A Kodak acid fix bath was used before washing and drying.

* * *

The author wishes to acknowledge the assistance of Harwood Kolsky, William S. Johnson, and Harry F. Schulte of the Los Alamos Scientific Laboratory. The work was done under the auspices of the U. S. Atomic Energy Commission.

Pm^{147} Point Source

By JOHN E. GATES and
DAVID F. EDWARDS*
Battelle Memorial Institute
Columbus, Ohio

To prepare a point source of promethium-147, electroplating onto the tip of a small-diameter wire was considered to be the simplest method.

A group at the University of Illinois† had published data on electroplating yttrium, neodymium, and lanthanum from anhydrous ethylene diamine solutions. Because of the similarity in the chemical properties of the rare earths, it appeared that the method used for electroplating neodymium might be used for promethium.

To test the procedure, 50 mc of Pm^{147} were purchased in the form of $PmCl_3$ in 1.0*N* HCl solution. A plating solution was prepared by evaporating the $PmCl_3$ solution to dryness and dissolving the residue in 98% ethylene diamine. This solution was added to a small-bore U-tube that was divided into two compartments by a porous glass disk. Dry nitrogen was bubbled into each compartment to provide agitation and an inert atmosphere. The anode and cathode were constructed from 0.020-in.-diameter platinum wire sealed in glass from which the ends of the wire extended 0.060 in. to provide the electrode surface. Electroplating was continued for approximately 46 hr at 90 volts and 70–90 μa.

At the end of the plating period, it was determined by radiochemical analysis of the plating bath that 43 ± 4.3 mc of Pm^{147} had been electroplated on the cathode. The deposit was black and adherent with little metallic luster. It was not established whether the deposit was the metal or the oxide. A thin plastic coating was applied to the source to protect the promethium deposit temporarily. It appears that this method could be used to prepare Pm^{147} point sources with curie-level intensities.

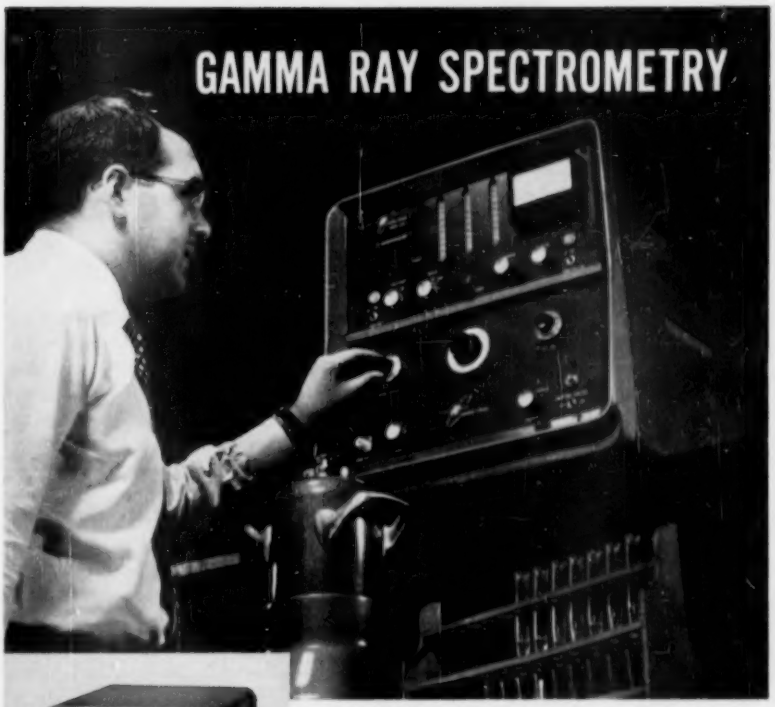
* * *

The authors wish to express their appreciation to G. D. Calkins and Meyer Pobereskin of the Radioisotope and Radiation Division, Battelle Memorial Institute, for their guidance in this research.

* Radioisotope and Radiation Div. and Solid State Devices Div., respectively.

† T. Moeller and P. A. Zimmerman, *Science* **120**, 539 (1954) and *J. Am. Chem. Soc.* **75**, 3940 (1953).

GAMMA RAY SPECTROMETRY



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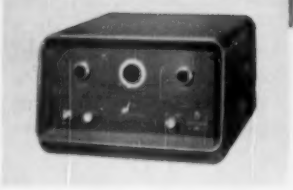

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Department of Chemistry, University of Michigan
Ann Arbor, Michigan

Multimillicurie sources of beta-emitting materials have found many uses during the past decade in biological (*1–5*), chemical (*6*) and physical (*7, 8*) systems. Investigators report using sources of phosphorous-Bakelite (*9, 10*), Sr^{90}-Y^{90} (*5, 11*), Ru^{106}-Rh^{106} (*4, 12*), Tl^{204} (*13*), and Pd^{109} (*8*).

Development in this laboratory (*14, 15*) of a new, rapid, high-decontamination method for the separation of silver by isotopic exchange makes possible the routine production of large beta-ray sources of Ag^{111} from neutron-bombarded palladium to supplement this list of sources.

Source Preparation

Palladium metal, when irradiated in a nuclear reactor, forms 13.6-hr Pd^{109}, 26-min Pd^{111}, and a small amount of 17-day Pd^{103}. The Pd^{111} decays to 7.6-day Ag^{111}. The Ag^{111} must be separated from grams of palladium, which is quite similar chemically to silver. Previous methods of separation proved tedious and not readily adaptable to high-level processing.

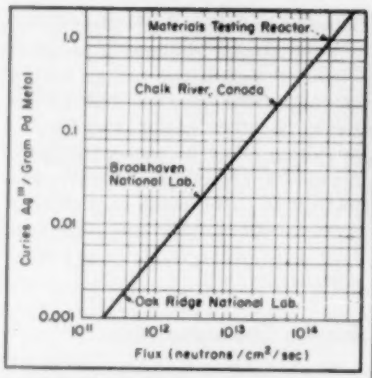
The separation of silver by isotopic exchange, however, is a very specific type of reaction that suffers little interference from macro amounts of palladium. Silver iodide is used since it suffers less interference from palladium than the silver chloride described previously. A "silver iodide" electrode is prepared and the electrode immersed in the radioactive solution to allow the process of isotopic exchange to occur and thus separate the radioactive silver from impurities. The silver iodide is then dissolved from the electrode and silver electrolysed from this solution as the metal on a platinum electrode of desired shape to form the source. For this final step, the silver may be plated on a variety of basic metals such as copper, brass, steel, nickel, and many ferrous and nonferrous alloys, as well as platinum (*16*).

To prepare the electrode, a platinum gauze about 1¼ in. high and ⅜ in. in diameter is coated with metallic silver by plating from 10 ml of solution containing 10 mg of silver as the nitrate in 3*M* NaCN and 0.5*M* NaOH. The plating process requires about 4 min at 3 volts and results in the deposition of about 5 mg of silver. The electrode is washed with water for 30 sec and immersed in 10 ml of a solution 0.05*M* in HI and 0.05*M* in $NaHSO_3$. The current is then reversed, the silver surface used as the anode, and electrolysed at 1½ volts for about 5 min, changing the silver to silver iodide. The finished electrode is washed and can be stored in 1-1 HNO_3.

To separate radioactive silver from other activities (except halides) the silver iodide electrode is immersed for 5 min at room temperature in about

Comparison of Beta-Ray Sources

	Half-life (17)	*Radiations (Mev)* (17) β^-	*Radiations (Mev)* (17) γ	*Form*	*Specific activity used or available (curies/gm)*	*Personnel hazard* (18,19)	*Combustible?*	*How obtained*
Pd^{109}-Ag^{109m}	13.6 hr	Pd 0.961 Ag e^-	None 0.087	Metal foil	0.2–100 (X-10, MTR)	Low	No	Neutron-irradiated Pd metal
Ag^{111}	7.60 day	1.04 (91%) 0.80 (1%) 0.70 (8%)	0.340 (8%) 0.243 (1%)	Ag metal electroplated on metal cathode	1–1,000	Low	No	Neutron-irradiated Pd^{111} in palladium
Pd^{32}	14.30 day	1.701	None	Red phosphorus mixed with Bakelite	~0.0058 (X-10)	Low	Yes	Neutron irradiation of plaque
Ru^{106}-Rh^{106}	1.0 yr	Ru 0.0392 Rh 3.53 (68%) 3.1 (11%) 2.44 (12%) 2.0 (3%) others (6%)	None 0.513 (23%) 0.624 (12%) others (3%)	Ru metal electroplated on Cu, Pt, Au or Ni cathode and covered with thin layer of silver for protection	~20	Intermediate	No	Fission products
Tl^{204}	4.1 yr	0.765 (98%) EC (2%)	None	Thallium salt or metal	0.02	Low	No	Neutron irradiation of thallium
Sr^{90}-Y^{90}	19.9 yr	Sr 0.61 Y 2.18	None None	$SrCl_2$ in vials or sealed in plastic or metal with thin window	~200 (carrier free)	High	No, but easily ruptured	Fission products



SILVER-111 ACTIVITY attainable in 1-week bombardment at different neutron-flux levels

10 ml of an acid solution containing the active material. The solution may be stirred magnetically. The electrode is then removed and washed with a stream of 1-1 HNO_3 for 1 min, the thorough wash being essential when high decontaminations are required. To form the Ag^{111} source the electrode is again immersed in the alkaline cyanide bath and the silver iodide coat dissolved; the silver is plated on a source holder of platinum or other metal.

Sources prepared in this way give an adherent coat of metallic silver. Contamination by rub-off may be lessened by plating a thin coat of inactive silver over the active silver. When silver is used as the support for the silver halide surface, much poorer deposits are obtained. It is also possible to use the silver iodide electrode directly and eliminate an extra step in the procedure. The silver iodide tends to be somewhat chalky and brittle, however, and would require a heavier coating than does the metal to prevent it from contaminating materials it touches.

These sources can be prepared in any of a number of shapes and forms from a point to a line or a cube or a gauze, or an irregularly shaped object merely by changing the shape of the cathode in the final plating step.

Yields of the radioactive silver vary with the type of electrode used in the exchange step. For the platinum gauze used in these experiments, greater than 98% yield was obtained in 10 min at room temperature. Increasing the temperature decreases the time required to obtain this yield. Smaller amounts of inactive silver may be used on the gauze if a source of very high specific activity is required. When submilligram amounts of silver are used, near-quantitative yields are not obtained be-

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cause of chalking of the silver iodide.

Concentrated solutions of palladium inhibit this exchange process only at concentrations greater than $0.5M$. Similarly, other foreign ions have an inhibiting effect at concentrations of about $2M$ and above. Results of a number of experiments on yields, decontaminations, and interferences using this procedure will be reported elsewhere.

Source Characteristics

The only silver isotopes present in a freshly bombarded sample of pure palladium would be the short-lived isomers of 44-sec Ag^{107} and 39-sec Ag^{109} in addition to the 7.6-day Ag^{111}. Unfortunately "high-purity" palladium often contains some silver metal impurity [see typical analysis (*8*)], which would give small amounts of 270-day Ag^{110} by neutron capture. A typical impurity of 0.002% silver would give only about 0.002% as much activity of this long-lived isotope as of the 7.6-day activity in a one-week bombardment, and would be negligible. Thus the primary silver activity present in these sources will be Ag^{111}.

A source of pure Ag^{111} would weigh only 6.5×10^{-9} gm/mc, but since several mg of silver carrier are required to utilize this exchange method, the silver will not be carrier-free.

The Ag^{111} emits several β-rays of about 1 Mev and ~10% γ-rays of about 0.3 Mev. The surface density of silver metal is about 26 mg/cm²/mil. Thus, the "half-thickness" for the silver β-rays is about 2¼ mils of silver. ("Half-thickness" is useful for our discussion, although it admittedly is not very exact.) Since in this procedure 10 mg or less of silver carrier is used, at least half of all the β-rays emitted will not be absorbed in most source arrangements. Hence, much less activity is lost by absorption in these silver sources than in the P^{32} plaques.

The most active source made to date in this laboratory has been several millicuries, but the same procedure is suitable for many curies with the same amount of carrier. The graph shows the amount of Ag^{111} per gram of Pd that may be obtained in a 1-week irradiation at various reactors. Reactors such as the NRX at Chalk River and the MTR in Idaho can accept up to 50 or more grams of palladium in their high-flux position. Thus, multicurie sources could be made by this exchange procedure. Regardless of the activity level of the Ag^{111}, the

source can still be kept in an easily handled form.

Comparison of Sources

Characteristics of a number of kinds of beta-ray sources are listed in the table. Sr^{90} suffers the major disadvantage of difficulty of mounting and of high personnel hazard. P^{32} has been used extensively in Bakelite plaques for many types of irradiations—especially in the biological and medical field, but is inherently bulky and prone to contamination.

Sources of Ag^{111} compare favorably with the other sources. The 7.5-day half-life is some disadvantage, but the ease of preparation should offset this. In its favor is the possibility of preparing multicurie sources in any of a multitude of shapes that best fit the material or object being irradiated. Since silver is relatively nontoxic (*20*) in small concentrations, it does not present the problems of Sr^{90}. The γ-ray associated with the silver β-ray is of low energy and low abundance and should have a negligible effect on handling.

• • •

This work was supported in part by the U. S. Atomic Energy Commission. The radioactive palladium used was obtained through the Isotopes Division of the Commission, Oak Ridge, Tennessee.

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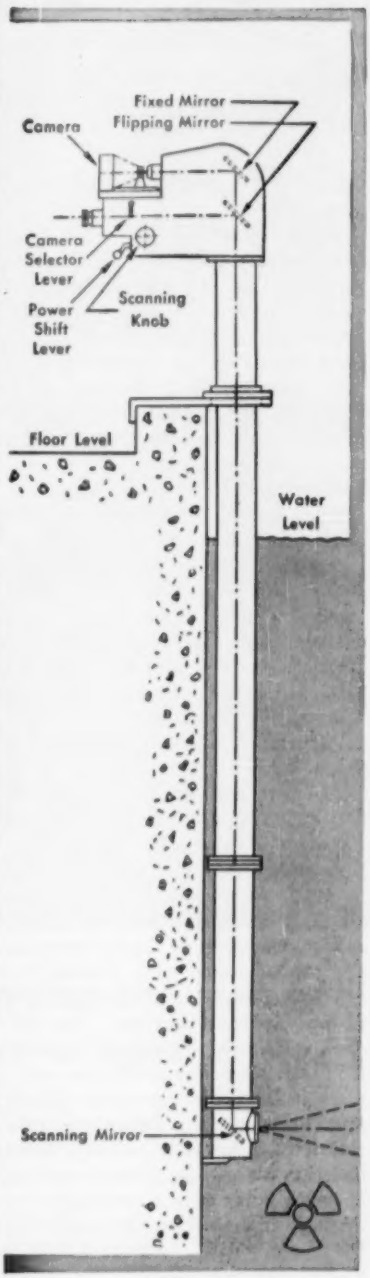

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Production of Fluorine-18

By H. O. BANKS, JR.
The Hot Laboratory
Brookhaven National Laboratory
Upton, New York

Knight *et al.** produced fluorine-18 by the following reaction using thermal neutrons

$$_3Li^6 + {}_0n^1 \rightarrow {}_1H^3 + {}_2He^4$$
$$_1H^3 + {}_8O^{16} \rightarrow {}_0n^1 + {}_9F^{18}$$

This work has been repeated and verified by the author.

The following procedure gave a greater chemical yield than that obtained with the procedure reported by Knight, and at the same time gave a product that would be physiologically compatible and therefore suitable for medical research.

Chemically pure lithium nitrate was fused and small increments poured into molds yielding buttons of about 0.4 gm each. While still anhydrous, these buttons were heat sealed into 1-in.-square polyethelene envelopes. Each envelope was then irradiated, with thermal cooling, for 112 min in the Brookhaven reactor.

Immediately upon removal from the reactor, the envelope was cut off and the button dissolved in water. Then fluoride carrier (KF), aqueous lead acetate, and concentrated hydrochloric acid were added to precipitate lead as chlorofluoride or chloride.

The precipitate was dissolved in aqueous 25% sodium hydroxide and made just acid by adding 10% sulfuric acid. Here, the lead precipitates out as lead sulfate leaving the fluoride in solution. The mixture was centrifuged and the supernate decanted. The solution was made just basic with aqueous potassium hydroxide and in this form constituted the product.

Decay curves of six different samples, plotted on semilog paper, showed a straight-line decay, with a 112-min half-life and no tail after eight half-lives, indicating high radiochemical purity of the product. Extrapolated to T_0, at the end of the irradiation the yield for 0.4 gm of starting material was 0.4 mc of F^{18} at a flux of 3.6×10^{12} n/cm²/sec.

While as much as 1 mc of F^{18} could be successfully purified by the foregoing process, it did not work for amounts of starting material in excess of 1 gm. Higher concentrations of lithium nitrate prevented the precipitation of lead chlorofluoride.† Further, at a flux of 3.6×10^{12} n/cm²/sec, amounts of lithium nitrate in excess of 10 gm partially decompose due to the internal heat evolved from the nuclear reactions.

After testing other lithium-oxygen compounds, lithium carbonate was selected because of its high thermal stability and because it gave a F^{18} yield at least as great as the nitrate. The availability of this compound in high chemical purity greatly minimizes the formation of radiocontaminants. After a 24-hr irradiation, 2 mc of F^{18} per gram of starting material is produced.

The revised separation consists of first dissolving the irradiated lithium carbonate in nitric acid. Carrier fluoride is then added in the amount of 10 mg F^- per 4 gm of lithium carbonate. Calcium ion is then added and calcium fluoride and calcium hydroxide are coprecipitated with sodium hydroxide and separated from the lithium nitrate by centrifugation. The calcium hydroxide is dissolved in acetic acid and a second centrifugation separates it from the remaining calcium fluoride precipitate. This calcium fluoride is then dissolved in acid, diluted and run through a suitable ion exchange column into a potassium hydroxide solution where it constitutes the final product. An over-all yield of 80–85% can be expected. The process requires 1.5 hr to perform.

This isotope is now available from Brookhaven National Laboratory in amounts up to 10 mc. Cations other than potassium may be had.

* * *

The author wishes to thank Mr. L. G. Stang, Jr. for referring the problem to him and for his continued interest in the work. This work was done under the auspices of the U. S. Atomic Energy Commission.

* Radiochemical Studies of the Fission Products, Coryell and Sugarman, NNES Vol. IV (9) Book 3, p. 1916.

† "Scott's Standard Methods of Chemical Analysis," 5th edit., Vol. 1, p. 405, note 12 (D. Van Nostrand Co., New York).

NEWSMAKERS

W. W. Grigorieff, chairman of the university relations division of the Oak Ridge Institute of Nuclear Studies, was elected first permanent executive secretary of the American Nuclear Society. He succeeds William M. Breazeale, Pennsylvania State University, who acted as interim executive secretary since the founding of the Society in Jan. '55. The office of the secretary is in the ORINS administration building (P. O. Box 963, Oak Ridge, Tenn.).

Pieter Von Hermann is the first recipient of the $1,500 Atomic Development Mutual Fund fellowship at Yale University. He will study the gamma emission of cyclotron-produced radioisotopes.

Carl Flesher, formerly of the World Bank staff, has been named an assistant director of AEC's reactor development division. He will be in charge of the Commission's international programs.

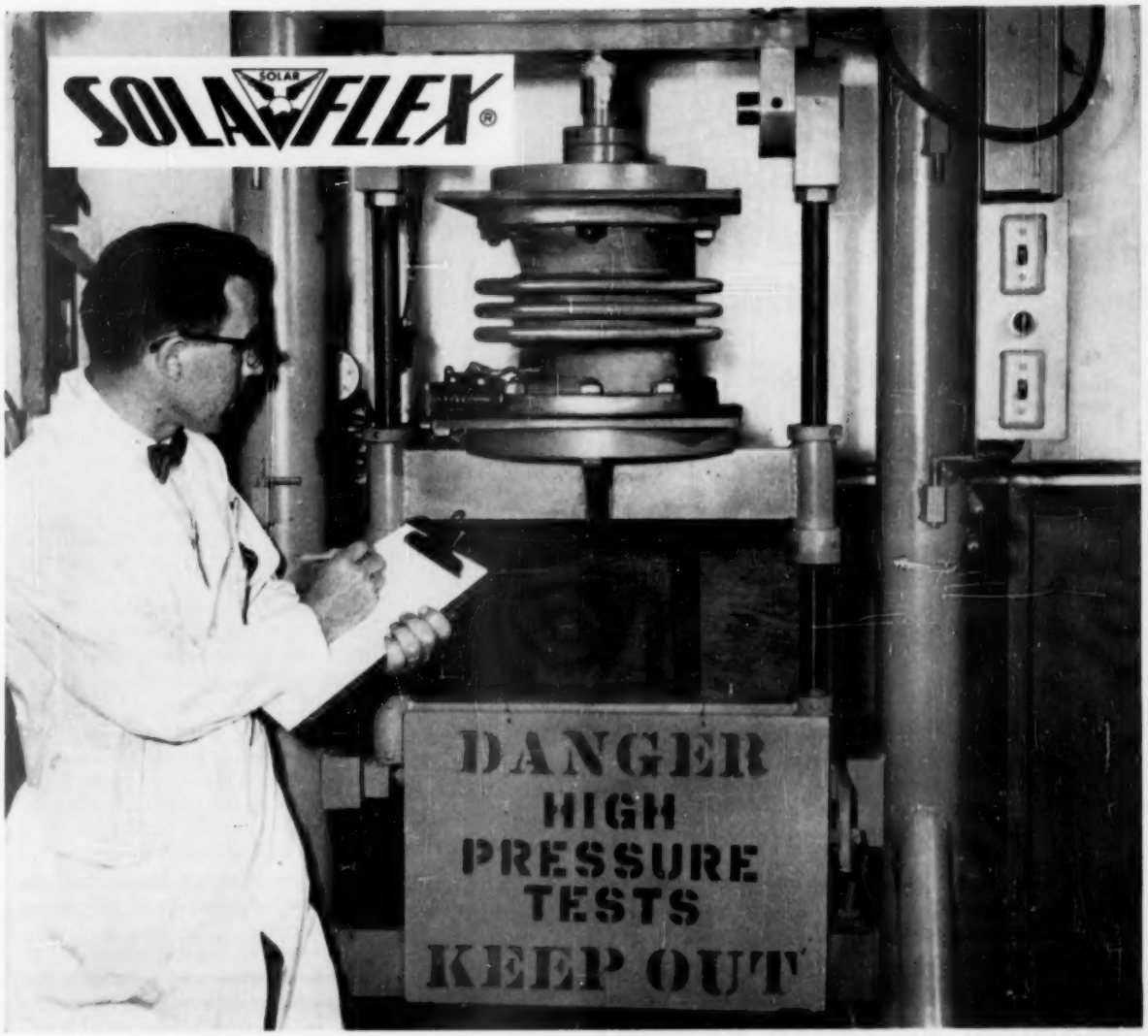
Joseph C. Boyce, formerly associate director of Argonne National Laboratory, has been appointed by Illinois Institute of Technology to be its vice president of academic affairs and dean of the graduate school.

Harold E. DeBolt, formerly with the nuclear power division of the Navy's Bureau of Ships and the Naval Reactor Branch of AEC's Reactor Development Division, heads the newly formed nuclear instrumentation department at Fairchild Camera and Instrument Corporation. **Louis C. Prisco** is sales manager; he had been manager of nuclear sales of the Anton Electronic Laboratories.

Henry B. Fry, assistant manager for administration and service of AEC's Santa Fe operations office, has been named director of administration for the General Atomic Division of General Dynamics Corporation.

Alberto F. Thompson has been named Head of the Office of Scientific Information of the National Science Foundation. AEC Chief of Technical Information for the past seven years, he was in charge of the U. S. Geneva exhibit.

J. E. Hudgens, Jr., formerly of the AEC New Brunswick Laboratory, has joined the Atomic PowerDivision of the Westinghouse Electric Corp. as technical staff assistant to the chemistry subdivision manager.



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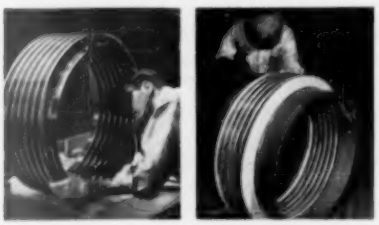

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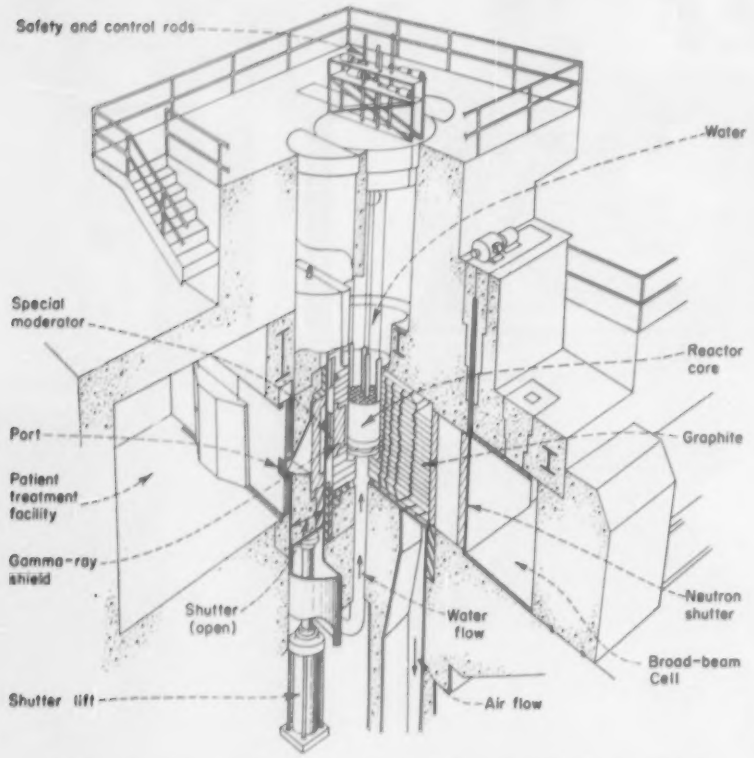

FIG. 1. Proposed arrangement of core, shielding, and irradiation facilities

The Proposed Brookhaven Medical Research Reactor

By J. S. ROBERTSON, E. STICKLEY, V. P. BOND, and L. E. FARR
Medical Department
Brookhaven National Laboratory
Upton, L. I., New York

Attainment of adequate depth doses of irradiation within desirably short time periods for medical and biological studies requires a thermal-neutron beam having a flux of 10^{10} to 10^{11}n/cm²/sec. This and other radiation requirements are expected to be met by a reactor operating at up to 1 Mw power. A proposed design is presented to show how a reactor using "swimming-pool" type fuel elements and an air-cooled graphite reflector-moderator could be used to meet the given radiation-source requirements.

Need for Medical Reactor

Increasing demands from Brookhaven National Laboratory's Medical Department for sources of neutrons and for other types of radiation suitable for studying the biological effects of radiation and for investigating clinical uses, have led to the proposal of a reactor designed to meet these specific requirements. The proposed reactor is being planned as an integrated unit of the forthcoming new Brookhaven National Laboratory hospital and medical research complex. The radiation requirements for certain investigations and a preliminary reactor design are presented.

Present facilities. The Medical Department's needs are provided by two facilities of the Brookhaven National Laboratory research reactor. One facility, on the west face of the reactor, consists of a port 5-cm square extending through the shield. It provides a collimated external thermal-neutron beam with a flux of 10^7 neutrons/cm²/sec. It has been used chiefly for instrumentation studies and for irradiation of small animals.

The second facility is on the top of the reactor and provides a thermal-neutron flux of 3×10^9n/cm²/sec at its 10×10-cm. port. Its higher flux is explained in part by its port being only 107 cm from the graphite reflector of the reactor (the upper 107 cm of concrete shielding is removed while the facility is in use) and by the fact that, instead of giving a collimated beam, the 10-cm-square port "sees" an area of graphite 120 cm square, thus giving a diverging beam, but one with a higher flux. Interposed between the port and the graphite reflector are a layer of bismuth, which serves as a gamma shield, and a massive motor-driven shutter, which is primarily a neutron shield when in the closed position (*1*). Use of the shutter makes it possible for personnel to work for limited periods of time in the pit formed by removal of the upper shielding blocks, without necessitating reduction of the reactor power level.

However, those experiments that do not allow replacement of the shielding blocks during the time when the shutter is open must be conducted at times when the effect of the neutron beam on the background does not disturb experiments at other facilities of the reactor. In addition, the neutron flux at this facility occasionally has been changed during an experiment because the operating characteristics of the reactor (power level, control-rod position, etc.) have had to be changed to meet the requirements of some other experiment. These difficulties arise primarily from the fact that the research reactor is better designed for physical than for biological research. In particular, the demand for a high thermal-neutron flux in an external beam, characteristic of the requirements for biological research, was not fully anticipated.

The second facility has been used as the site of treatment for two series of patients with glioblastoma multiforme, a malignant type of brain cancer. These patients have been treated by neutron-capture therapy, using the

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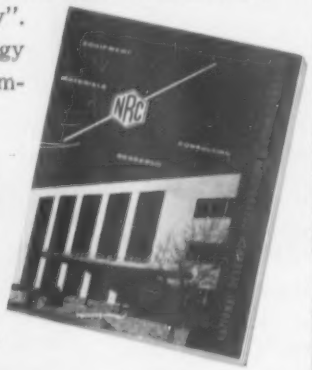

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CARBOLOY CREATED-METALS FOR INDUSTRIAL PROGRESS

$B^{10}(n,\alpha)$ reaction. In the first series of ten patients (*2*, *3*), a 5 × 10-cm treatment port was used. The shutter had not been installed, and it was necessary to control the flux by turning the entire reactor on and off. In the second series of patients, the present higher flux and shutter along with higher doses of boron have been used, and an improvement in the clinical results is currently being observed (*1*, *4*).

Fluxes and facilities needed. The accumulated experience with neutron-capture therapy indicates the need, for medical applications, of an external beam with a thermal-neutron flux of 10^{10}–10^{11}n/cm²/sec. in a 10-cm-square port. These high port fluxes are needed to provide effectively high fluxes at the tumor depth (*5*) and, in some applications, to take best advantage of the short period of time during which the concentration of the target materials in the tumor is optimal.*

For certain studies, the thermal-neutron beam should be as free as possible from fast neutrons and gamma rays, but for others it should be possible to obtain epithermal neutrons, or to include a fission plate or other converter providing fast neutrons or gamma rays as may be desired. A separate but similar facility is desired for animal studies and for testing proposed modifications for patient irradiation.

Different facilities are desired for certain other lines of investigation. There is a requirement for a broad-beam facility to permit whole-body irradiation of large animals or of large numbers of small animals, with neutrons of various energies and with gamma rays. This facility would be used in studies of the relative biological effectiveness of the various kinds of radiation and in pre- and post-protection studies with slow neutrons and heavier particles resulting from neutron-capture reactions. There will be an especially high-flux facility for microbiological studies.

The medical research reactor will not be used to produce those isotopes available from the Brookhaven National Laboratory research reactor or from other sources. However, the present plans include a facility for the production of certain special isotopes having very short half-lives and for which

* For example, in the treatment of brain tumors by neutron-capture therapy, selective irradiation of the tumor is achieved, not because of selective uptake of the target material, but because the uptake by the tumor occurs sooner than that by the normal brain, so that there is a transient concentration difference.

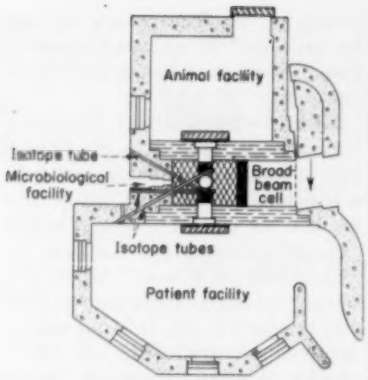

FIG. 2. Proposed arrangement of irradiation facilities with respect to the location of the reactor core

clinical applications are contemplated.

Elimination of other devices. Before the decision to request the medical research reactor was reached, a survey was made (under contract) for the Brookhaven National Laboratory by Nuclear Development Associates (NDA) of means for meeting the Medical Department's radiation-source requirements. Various accelerators and fixed sources were considered, but when all of the parameters of expected performance, versatility, safety, dependability, operational simplicity, security classification and cost were analyzed, the reactor emerged as being the most suitable instrument.

The Proposed Reactor

Some features of the present design are based on plans suggested in the pertinent NDA reports to BNL, while others have been developed by BNL's reactor operations, nuclear engineering, and architectural planning groups. Many engineering details are not firm.

Core and reflector. The proposed reactor will operate at power levels up to 1 Mw, will use "swimming-pool" type fuel plates, and will have air-cooled graphite as the moderator-reflector. The core will be light-water cooled.

The proposed reactor is shown in Fig. 1; facility layout is in Fig. 2.

The reactor core will contain the fuel elements, control rods, and cooling water. The control rods will be raised out of the core when the reactor is in operation. The control-system design will employ standard components that, in many respects, will be like those used in the Oak Ridge National Laboratory Bulk Shielding Facility (*6*).

The graphite reflector will surround the core on all sides except the top. To dispose of the A^{41} generated in the

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cooling air, an exhaust stack adequate for disposal of the activated air arising from continuous operation at 1 Mw is planned.

Experimental facilities. The shielding problems involved in providing a high thermal-neutron beam with relatively low gamma and fast-neutron fluxes at the patient treatment facility are still being studied. To meet the requirement for a means for varying the neutron-energy spectrum from thermal to about 8 kev, it is planned to interpose a device in which it will be possible to substitute various quantities of other moderators for the graphite. To control the radiation while the reactor is at power, a hydraulically operated shutter will be provided as shown in Fig. 2. The entire patient treatment facility essentially will be duplicated on the opposite face of the reactor for animal irradiation and for testing proposed modifications.

One of the remaining faces will be used as the broad-beam animal-exposure facility. A movable neutron filter and a device for producing fast-neutron or gamma radiation will be provided.

Reactor safety. For safety, it is expected that the entire reactor, treatment, and observation areas will be contained in a steel cylindrical tank or equivalent structure, and that entrance to the reactor building will be through air-locks. These safety features may be regarded as extra precautions. The maximum excess reactivity is expected to be kept so low that, in the worst possible accident, if all of the control rods are instantaneously withdrawn, the reactor power will rise slowly enough to give the safety mechanisms ample time in which to operate before an abnormally high power level is obtained; even if the scram mechanisms fail, the resulting disturbances will not attain damaging proportions.

* * *

The research upon which this article is based was supported by the U. S. Atomic Energy Commission.

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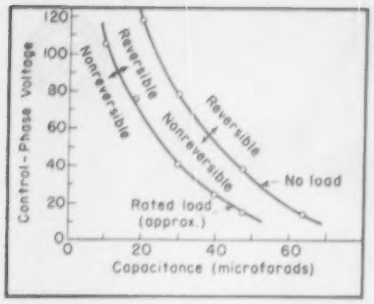


FIG. 1. The critical control phase voltage is diminished by increasing either the control circuit capacitor (either intentionally or by aging) or the motor load

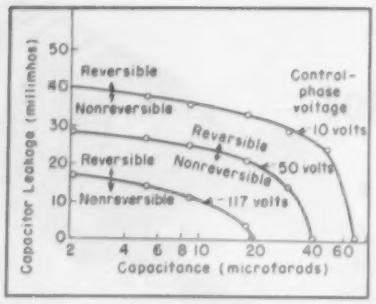


FIG. 2. With no load on the shaft, for a given-size capacitor in the control circuit and a given amount of leakage through this capacitor, there is a critical control-phase voltage below which the motor will not reverse

How to Use Two-Phase Servomotors to Drive Reactor Shim Rods

By D. R. WHITEHOUSE, F. W. BRADLEY, A. S. HOFFMAN, and R. C. REID
M.I.T. Engineering Practice School
Oak Ridge, Tenn.

Although not presently used extensively for driving reactor shim rods, ordinary two-phase servomechanism motors offer the advantages of having moderate cost, ready availability, and excellent braking characteristics (due to the armature's low inertia).

Preliminary experiments demonstrated that, under certain conditions, two-phase servomechanism motors run from a single-phase supply with a capacitor in one of the stator windings fail to reverse direction when the stator leads are interchanged (plugging). Test conditions were not defined sufficiently to predict when a motor would or would not reverse. To enable such predictions, experiments were made with several Diehl servomotors to determine their reversibility characteristics in terms of motor load, phase-shift capacitor size, capacitor aging (or leakage), and size of the control-phase voltage.

Results

The motors were run from a single-phase supply with one stator phase operated at a constant 115 volts while the second stator phase (the one with the capacitor in series with the stator winding) was operated with varying voltage. This latter voltage is referred to as the "control-phase" voltage.

Two important observations are made in Figs. 1 and 2, which are for an SS-ZP-105-2212-1, 200-watt servomotor.

These results do not give any indication of the proper choice of capacitor either for maximum efficiency or speed. They merely indicate whether the given motor will reverse for a chosen value of capacitance. The probability that the motor will fail to reverse is determined by the probability that the operating point will shift to the nonreversing region.

Discussion

The relationship between control-circuit impedance and rotor resistance will determine whether a positive single-phase torque may be developed in the motor. With R = rotor resistance, Z = total control-phase impedance in series with the equivalent rotor reactance, and S = actual speed divided by synchronous speed, then (a) if $R > |Z|$, no positive single-phase torque is developed; (b) if $R < |Z|$, positive single-phase torque is developed for*

$$0 < S < [1 - (R^2/|Z|^2)]^{1/2}$$

Thus, servomotor rotors are designed with high resistance so as to eliminate single-phase operation.

When a capacitor is used in the control circuit to obtain the proper phase shift, the capacitive reactance must be added to the total control-circuit impedance. If this additional reactance is too large, the motor will be able to run single phase. Thus, for small capacitors a larger control voltage is needed to reverse the motor. A moderate increase in capacitor leakage will decrease the effective impedance of the control circuit so as to allow reversing action for an otherwise too-small capacitor. The curves for zero control-phase voltage define the boundaries for single-phase and stalled operation, and were obtained for smaller size motors. But, for the 200-watt motor described here, a minimum control-phase voltage of 10 volts was used because the motor had a tendency to run very slowly in one direction even with zero control-voltage and infinite leakage (shorted control winding).

* R. Koopman, "Operating Characteristics of Two-Phase Servomotors," *Transactions AIEE* **68**, Part I, 319 (1949).

Why Use Single-Phase Power Supply?

There is some uncertainty concerning the reliability of servomechanism motors because of their reversing characteristics.

Reversing ordinarily is carried out by interchanging the two stator phases or, with a two-phase supply, by reversing the polarity of one of the phases.

In reactor control, the need for providing a two-phase supply is a disadvantage. Although the probability of phase shifting at the source is remote, such an accidental occurrence would reverse all shim-rod motors, and would result in a dangerous condition. Thus, the phase relationship must be monitored.

Running each motor from a stable single-phase supply with a phase-shifting capacitor in one of the stator phases would be more acceptable. In this case, each shim-rod control motor would be independent of the others—and would be related only through the need for power for operation. Also, secondary emergency sources of single-phase power usually are more readily available than those supplying two-phase power. Consequently, in any proposal to use two-phase servomechanism motors to drive reactor shim rods, it is desirable to use a single-phase power supply.

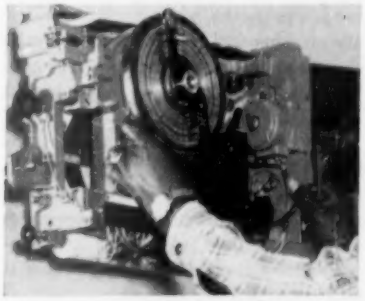
An increase of load on the motor shaft is an increase of negative torque. Thus the required control-phase voltage for reversal is reduced. With a given capacitor, the minimum allowable control-phase voltage for positive reversibility is determined by the conditions of no load and zero capacitor leakage. Thus, if the operating point is positioned in the reversible region of Fig. 1, the motor will reverse under all conditions of load and leakage and failure probability is determined solely by the probability that voltage variation, capacitor variation, or leakage will shift the operating point into the nonreversing region. In reality, the two regions are not divided by a curve of infinitesimal thickness, but a band whose thickness is determined by such other variables as ambient-temperature variations and reference-voltage variations.

* * *

This note is abstracted from KT-200, Carbide and Carbon Chemicals Company, Oak Ridge, Tenn. The work was carried out as an Massachusetts Institute of Technology Engineering Practice School problem in conjunction with the reactor controls division of Oak Ridge National Laboratory.

REACTOR FACTS

10% of power from Calder Hall reactors goes to circulate CO_2 coolant. Since 70–75% of the pressure drop is in the reactors, modifications to the fuel elements and their fins could reduce the blower power required.



TEMPERATURE MAP of Hanford production reactor is obtained within minutes with aid of instrument that senses temperatures at rate of 3/sec. Analog-to-digital converter is first step; signal is translated from Brown recorder through coding switch shown above. Switch both controls automatic typewriter (Flexowriter) that prints data from "thousands of thermocouples" and it also codes digital signal into tape for later entry on IBM cards. Donald Stevens of General Electric's pile engineering unit developed the switch and the circuitry; Fischer-Porter Company supplied the Flexowriter

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1/4	48 x 48*
3/8	
1/2 & Up	

* Can be furnished in 1/2 sheets

ROD

DIAMETER INCHES	
1/4	1
5/16	1 1/16
3/8	1 1/8
7/16	1 1/4
1/2	1 3/8
9/16	1 1/2
5/8	1 3/4
3/4	2
7/8	2 1/4
	2 1/2
	3

Other diameters on specification

TUBING

TYPICAL SIZES INCHES	
O. D.	I. D.
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1	3/4
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2 1/2	1 1/2
3	1 3/4

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BOOKS

Materials for Nuclear Power Reactors

By HENRY H. HAUSNER and STANLEY B. ROSOFF (Reinhold Publishing Corp., New York, 1955, xxxi + 224 pages, $3.50).

Written at a level understandable to students and executives new to the reactor industry, this pocket-size book fills a need as an introduction to reactor materials. But, because the explanations are intended for the novice, the general level limits the depth of the volume's usefulness and lessens its value to persons generally knowledgeable in the nuclear field.

The first five chapters introduce the reader to the subject of reactors—types, components, and general materials considerations. Each of the next six chapters explains a specific use for the materials: fuels, moderators and reflectors, coolants, control elements, shields, and structural materials. The concluding chapter treats methods and equipment used for handling and disposing of radioactive materials. A listing of thermal-neutron absorption cross sections and a glossary make up the appendices.

More careful referencing and inclusion of data available since the UN's Geneva conference would make any future edition of this book of solid technical value—both to newcomers and to more experienced persons.

Although, as it stands, the book is well written and the explanations are quite clear, more liberal use of illustrations would facilitate the reader's grasp of reactor fundamentals, types, and applications.

Liquid-Metals Handbook—Sodium-NaK Supplement

CAREY B. JACKSON, editor (U. S. Government Printing Office, Washington, D. C., 1955, vii + 445 pages, $2.00). Reviewed by O. E. DWYER, Brookhaven National Laboratory, Upton, New York.

The third edition of the "Liquid-Metals Handbook" deals only with sodium and potassium-sodium alloys (NaK), whereas the two previous editions covered liquid metals in general. This is because of the fact that since the second edition was published (June, 1952), a great deal of information has been obtained on, and relative to the handling of, Na and NaK, as a result of the research and development work done under the Naval Reactors Program. Information obtained on other liquid metals during the past three years has been comparatively slight.

Whereas the second edition had a total of 269 pages, the third has 445. It is felt that the book could have been shortened a bit by simply referring to the literature on some of the less important details instead of discussing them at length in the text. Furthermore, it is felt that the article on flow characteristics could have been omitted, since the fluid dynamics of Na and NaK are no different from those of ordinary fluids.

The "Liquid-Metals Handbook" is not really a handbook, i.e., a compilation of tables and charts giving scientific and engineering information, but a collection of articles by experts in their fields on those subjects of interest to engineers concerned with the design and operation of engineering equipment for handling liquid Na and NaK. There are 30 separate articles by 51 authors arranged into six chapters—*Properties*, *Fundamentals*, *System Design*, *Components*, *Safety and Fire Protection*, and *Applications*—each having its own editor.

Owing to the fact that the Handbook is a collection of separate articles, some topics get treated in two or more places, with the result that some get too much attention while others do not get enough. The value of the book as a handbook suffers because of this. There is also some unnecessary duplication. Moreover, a great deal more cross-referencing would have been desirable. For example, in the heat transfer section of Chapter 2, there is less than half a page devoted to the important problem of estimating shell-side coefficients for shell-and-tube heat exchangers; while in the chapter on components there is over a page devoted to this same subject, each section making no reference to the other. When the whole subject is not presented in one section, it is likely that some particular topic may be inadequately treated. For example, the reviewer felt that perhaps the bridge between heat-transfer theory and heat-exchanger construction was possibly not given sufficient consideration.

Also, owing to the multiplicity of authorship, some sections are naturally better written than others. Among the particularly well written sections, in the opinion of the reviewer, are those on chemical and physical properties, thermal stress and thermal-stress fatigue, heat exchangers and steam generators, and instrumentation.

The book presents much more information on all phases of the science and technology of Na and NaK than was given in the previous edition. On the basic side, for example, the amount of space devoted to chemical and physical properties increased three-fold, while on the applied side, space given to information on the performance of engineering components and operating techniques increased even more.

In liquid-metal technology, the problem of heat-exchanger design is a very critical one. Consequently, there is a great deal more information on heat transfer and heat-exchanger performance in the third edition than in the first. Moreover, the material is better presented, although it is felt that the omission of the table of physical and thermal properties in engineering units from the third edition is a mistake.

Since most of the data and information presented were obtained in connection with the Naval Reactors Program, they pertain specifically to certain definite mechanical designs and operating conditions, and therefore, to some extent, do not have general applicability. For example, much of the heat-transfer information was obtained on submarine prototype units instead of an exchanger designed for the purpose.

There are several small errors and misprints in the book, most of which are obvious and evidently due to transcription from original manuscripts, which would undoubtedly be eliminated in a second printing.

The science and technology pertaining to Na and NaK are very extensive subjects. Although an impressive amount of information has been accumulated thus far, one is still impressed by the fact that a great deal still remains to be learned.

A very valuable feature of the book is the inclusion of extensive reference lists at the ends of the separate articles.

In spite of the minor criticisms given above, the handbook presents a lot of valuable information on all of the major subjects and topics pertinent to the handling of Na and NaK. It will be a most valuable reference for engineers engaged in the design, construction, and operation of equipment for use with these liquid metals.

BOOKS RECEIVED

Nuclear Radiation Detectors, by J. Sharpe (John Wiley and Sons, Inc., New York, and Methuen and Co. Ltd., London, 1955, 177 pages, $2.50). (*To be reviewed.*)

Principles and Applications of Physics, by Otto Blüh (Interscience Publishers, Inc., New York, 1955, xiv + 866 pages, $7.00). This book is written for students of the sophomore or higher college level. It gives a comprehensive view of physics—history, philosophy, and fundamentals of classical and modern physics—and can serve as a final text for students specializing in other fields than physics.

Niels Bohr and the Development of Physics, edited by W. Pauli (McGraw-Hill Book Co., Inc., New York, 1955, vii + 195 pages, $4.50). This collection of essays by outstanding physicists is dedicated to Dr. Bohr on his seventieth birthday. It summarizes the great developments in 20th century physics.

Atomic Energy Research at Harwell, by K. E. B. Jay (Philosophical Library, Inc., New York, 1955, xii + 144 pages, $4.75). This book describes the work done at the Atomic Energy Research Establishment at Harwell in the period 1951–54. Security-regulations changes permit more detailed discussion than was previously possible in "Harwell—the British Atomic Energy Research Establishment."

Reflections of a Physicist, 2nd edit., by P. W. Bridgman (Philosophical Library, Inc., New York, 1955, xiv + 576 pages, $6.00). The bulk of Bridgman's non-technical writings are contained in this volume.

Prospecting for Atomic Minerals, by Alvin W. Knoerr and George P. Lutjen (McGraw-Hill Book Co., Inc., 1955, ix + 211 pages, $3.95). This practical handbook for the prospector tells how to detect and recognize uranium ores, what are the best types of detecting instruments, how to stake a claim, and how to evaluate and sell the ore.

Static and Dynamic Electron Optics, by P. A. Sturrock (Cambridge University Press, New York, 1955, x + 240 pages, $5.50). This book is concerned with the various applications of charged-particle focusing. The first part, "static" electron optics, is important in electron microscopy and spectrometry. The second part, "dy-

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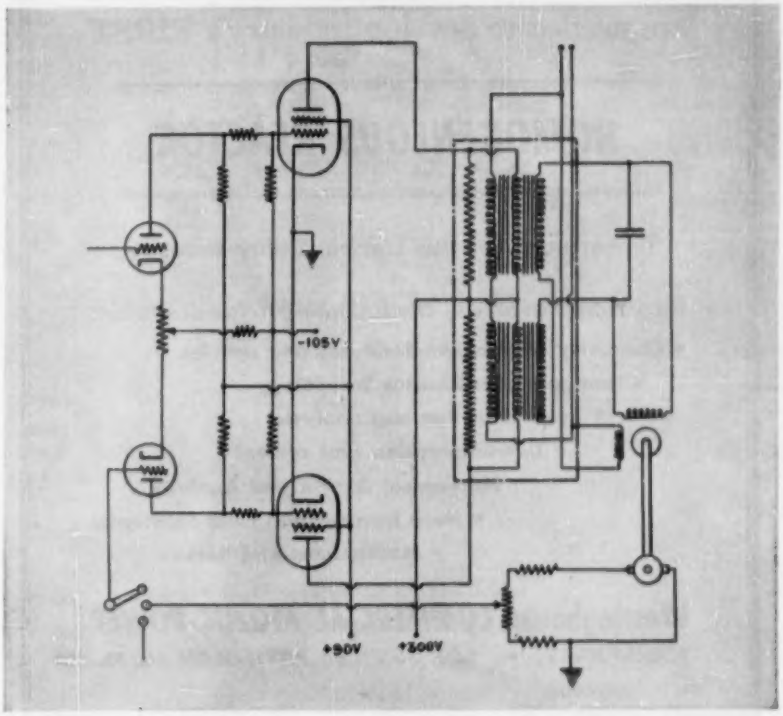

Servo Motor Control System

Most engineering ingenuity concentrates not on basic principles, which are relatively simple, but on the fine details that make the difference between good and poor design, between high and low cost, or between efficient and inefficient component arrangement. For instance, the motor control system patented by the Ford Instrument Company. The purpose of the system is to provide a sensitive control system to make an induction motor respond accurately to a relatively small reversible input signal. This system employs saturable-core transformers to combine the sensitivity of vacuum tube amplifiers with the high power-carrying capacity of saturated-core devices. This also facilitates the problem of matching the motor impedance with that of the amplifier.

In the circuit shown the first pair of tubes act as a phase inverter, with the control signal applied to the grid of one inverter tube. The feedback signal, produced by a d-c generator coupled to the controlled motor, is applied to the inverter tube. The output of the inverter is the signal of the servo loop. The second pair of tubes acts as a driver-stage for the saturated transformers that supply one winding of the controlled two-phase induction motor; the other motor winding is connected to the power line.

This is typical of the things Ford engineers do . . . every day. If you have a control problem it will pay you to talk to the Ford Instrument engineers.

83

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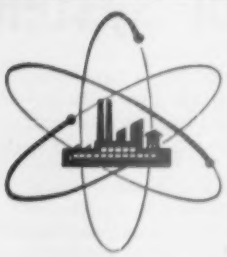

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namic" electron optics, is important for particle accelerators.

Boltzmann's Distribution Law, by E. A. Guggenheim (Interscience Publishers, Inc., New York, and North-Holland Publishing Co., Amsterdam, 1955, 61 pages, $1.50). This book is written for undergraduate students of physics and chemistry. The dependence of the equilibrium properties of bulk matter on temperature is derived by means of the law.

Atomic Physics, by Gaylord P. Harnwell and William E. Stephens (McGraw-Hill Book Co., Inc., New York, 1955, x + 401 pages, $8.00). This volume of the International Series in Pure and Applied Physics is written for first-year graduate students. Emphasis is on those quantum and classical concepts that characterize the physics of elementary particles.

Circuit Analysis by Laboratory Methods, 2nd edit., by Carl E. Skroder and M. Stanley Helm (Prentice-Hall, Inc., Englewood Cliffs, N. J., 1955, xvi + 376 pages, $5.75). Additional material in this new edition is on oscillographs, nonsinusoidal periodic waves, filters, magnetically coupled circuits, and network theorems.

Classical Electricity and Magnetism, by Wolfgang K. H. Panofsky and Melba Phillips (Addison-Wesley Publishing Co., Inc., Cambridge, Mass., 1955, xi + 400 pages, $8.50). This book serves as background for the study of experimental physics and the quantum theory. Theory is developed from an empirical basis rather than by postulation and logic.

Handbook of Engineering Materials, edited by Douglas F. Miner and John B. Seastone (John Wiley and Sons, Inc., New York, 1955, xi + 1124 pages, $17.50). This handbook serves as a single source of data on manufacturing and construction materials. Offering a wide variety of material, it cannot cover specific topics exhaustively. There are four sections on general information, metals, nonmetals, and construction materials.

Chimie Physique Nucléaire Appliquée, by Jacques Errera (Sciences et Lettres, Liège, 1955, 226 pages). The first section of this book is a general discussion of the atom, the nucleus, and nuclear reactions. The second part contains the physical-chemical applications of

nuclear radiation, together with the necessary techniques.

ALSO OF NOTE

Nuclear Physics. This new monthly journal, scheduled for Nov. '55 publication, is devoted to experimental and theoretical nuclear studies, nuclear fields, and fundamental aspects of cosmic radiation. It is tentatively planned to have a 700-page annual volume. L. Rosenfeld is editor. Subscription rate is $15.00 per volume, postage free. *North-Holland Publishing Co., Amsterdam (U. S. distributor: Interscience Publishers, Inc., New York).*

The Atom in Our Hands. This 44-page booklet describes some of the work being done at Oak Ridge National Laboratory—separation of uranium-235, radioisotope production and application, and reactor design. *Union Carbide and Carbon Corp., Room 308, 30 E. 42 St., New York 17, N. Y.*

Radiation Hazards in Firefighting. This pamphlet (Technical Bulletin No. 4 of the Safety and Fire Protection Branch, U. S. Atomic Energy Commission) is written for the firefighters at atomic energy installations and for municipal firefighters who may encounter situations where industrial radioactivity is a hazard. It is confined to peacetime hazards. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $.35.*

Atomic Industry Reporter. The Reporter provides three sections on a subscription basis: News and Analysis (weekly news report), Laws and Regulations (legislation and regulations as they are issued), Technology Reports (available technical papers). *The Bureau of National Affairs, Inc., 1231 24th St., N. W. Washington 7, D. C.*

Measurement of Vibration. This 64-page booklet covers the meaning of vibration terms, description of measuring instruments, procedures, and examples. *General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.*

Geneva Series on the Peaceful Uses of Atomic Energy. This series, under the editorial direction of J. G. Beckerley, will be published in spring '56 by D. Van Nostrand Co., Inc. Provisional titles for the six-volume series are: "Safety Aspects of Nuclear Reactors," "Power Reactors," "Research Reactors," "Nuclear Fuels," "Atomic Raw Materials," and "Applications of Nu-

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■

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- Electromagnetic properties of the upper atmosphere
- RF propagation in microwaves as concerned with antenna and radome research
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clear Radiation in Food and Agriculture." Prices are $7.50 per volume or $42.50 for the set.

Selected Scientific and Engineering Tables and Data. This 112-page booklet contains chemical and physical, engineering, plastics, bacteriological, leather, psychometric, and textile data. *United States Testing Co., Inc., 1415 Park Ave., Hoboken, N. J.*

Atomic Opportunities in New England. This is the proceedings of a meeting sponsored by the New England Council and Atomic Industrial Forum, Oct. '54. Topics covered are applications of atomic energy in electronics, metallurgy, agriculture, food processing, power generation, chemistry, and medicine. *Atomic Industrial Forum, Inc., 260 Madison Ave., New York 16, N. Y., $5.00.*

Atomic Energy—the New Industrial Frontier. This report covers a meeting sponsored by the Stanford Research Institute and Atomic Industrial Forum in San Francisco, April '55. Papers and discussions are on food and agriculture, reactors, nuclear power, related industries, and the Atomic Energy Act. *Atomic Industrial Forum, Inc., 260 Madison Ave., New York 16, N. Y., $5.00.*

Oak Ridge Institute of Nuclear Studies, 9th Annual Report. This report for the year ending June '55 gives financial data and work in the University Relations, Medical, Special Training, and Exhibits Divisions. *Oak Ridge Institute of Nuclear Studies, Inc., Oak Ridge, Tenn.*

Abstracts of the Literature on Semiconducting and Luminescent Materials and Their Applications. These abstracts were compiled by Battelle Memorial Institute and sponsored by the Electrochemical Society. They include foreign periodicals from Sept. '53 through Sept. '54 and domestic periodicals from Dec. '53 through Dec. '54. *John Wiley and Sons, Inc., 440 4th Ave., New York 16, N. Y., $5.00.*

The Protection of Workers Against Ionizing Radiations. This report was submitted to the Geneva Conference on the Peaceful Uses of Atomic Energy. It covers hazards, protective measures, and treatment and effects of radiation exposure in radiation use, as well as problems in uranium mining and shipment of radioactive material. *International Labor Office, 917 15th St., N. W., Washington 5, D. C., $.50.*

TECHNICAL ADVANCES

Separating Fission Products, U, by Recoil If fission takes place in a fuel grain smaller than the range of fission products, the recoiling products will separate completely from the parent material. This fact, used in early experiments on fission but largely neglected since, may form the basis for a practical separation scheme.

The minimum range of fission fragments is about 1.9 cm in air or 8 microns in U_3O_8. Richard Wolfgang, working in Brookhaven's chemistry department, prepared U_3O_8 particles under 1 micron in diameter by grinding and sedimenting. These were then suspended in a 3% gelatin solution and the whole chilled to maintain the particles in suspension (they tended to settle out of water suspension). The suspended fuel was then neutron-irradiated in the center of the Brookhaven reactor. After irradiation the gelatin was liquefied and the solid U_3O_8 grains separated from the solution. Essentially all of the fission-product activity was in the gelatin, none was left in the fuel grains, which showed a pure U^{239}-Np^{239} activity.

Thus one has a means of preparing pure actinide activities and carrier-free gross fission products. More importantly interest has been stimulated in reactor fuel schemes that permit physical separation of fission products from the fissile material. A case in point are the fluidized-fuel designs of Went and de Bruyn (NU, Sept. '54, p. 17).

Proportional Counting at 1-mm Pressure Proportional counter action with gas amplifications in excess of 10^4 at counting-gas pressures under 1 mm of mercury has been achieved by R. E. Zedler of ORNL's instrumentation division. He used both isobutane and amyl acetate as counter gases; good results were obtained with each. A wide variety of anode diameters, from 0.003 to 0.250 in. were employed, with brass cathodes of $1^{15}/_{16}$ and $2^{15}/_{16}$ in. i. d. Voltage required is of the order of 400–900 volts, depending on counter dimensions.

Fast Scale-of-Ten Vacuum Tubes Vacuum scaling tubes are being investigated in several laboratories as a potential competitor for ordinary tubes in fast multistate operation. Glow-transfer gas-discharge tubes have become increasingly popular for decade scaling, but, as is well known, they suffer from an inherent upper-frequency limit due to deionization time requirements. Thus, in an investigation at ORNL, H. N. Wilson found upper limits of 10 and 40 kc for the Erricson GC-10B and GC-10D types, respectively, and 100 kc for the Philips E1T. But even this is too slow for many requirements.

Using the vacuum-type Burroughs MO-10 as the input decade, Wilson was able to construct a scaler having 0.5-μsec resolving time. The succeeding two stages use GC-10/4B glow-transfer decades with 12AU7 drivers. Maximum repetition rate at the input is 20,000 pulses/sec, limited only by the mechanical register.

Beam-switching tubes (and related scaling types) are being pursued in several laboratories; commercial versions are the National Union LBS-10 and Haydu's 6700 (MO-10) and prototype DC-1R. This last is a decade-scaling tube with internal spade resistors, bringing maximum speed above 5 mc. Also available is the 1-mc H-B101 whose 22-volt operating voltage suits it to transistor circuits.

Taken with new secondary emission multipliers, pulse-height-analyzing tubes, numerical indicating tubes, etc. it appears that nuclear electronics may see some radical changes in the years ahead.

Russian Accelerator Men Look to 10^{12} ev At Geneva Russia's V. I. Veksler gave an evening lecture on their accelerator program. He revealed that construction is almost completed on a 10-Bev proton synchrotron. This would be the world's largest until projected strong-focusing machines at Brookhaven and CERN are completed. Looking ahead, he pointed out that, with existing limits on magnetic materials, energies above 50–100 Bev could not be achieved with known types; still he felt that ways would be found to reach 10^{12} ev.

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Patents

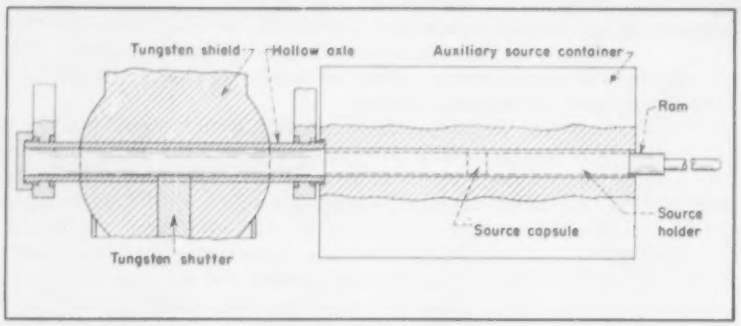


FIG. 1. Radiation-beam-forming shield and transfer container

Radioactive-Source Holder

According to John C. Pennock and Albert J. Bacchieri (U. S. 2,711,485, assigned to Tracerlab, Inc.), their radiation shield and collimator (Fig. 1) avoids the disadvantages of similar radiographic or therapeutic sources.

The device consists of a spherical beam-forming unit and a shielded container for transferring the source to the sphere. A cylinder contains the source between two shielding plugs. After the cylinder is loaded, it is inserted in a hole in the transfer container, and then pushed with a ram into the sphere.

The source cylinder is contained in the hollow axle of the sphere. The ends of the axle serve as trunions. The beam slot opens into the sphere and is closed by a shutter (the shutter mechanism is described in a pending patent application).

This unit avoids the hazards of power failure since the source does not have to be shifted during use. Direct transfer from container to shield does not involve having the source in an unshielded position.

Radioactive-Labeling Method for Solid Objects

In preparing solid objects for wear studies involving radioisotopes, neutron irradiation or fabrication from a radioactive material are often impracticable. The attendant amount of radioactivity would be unsafe or cause excessive expense.

Carroll L. Knapp, Jr., and James F. Black suggest in U. S. 2,711,484 (assigned to Esso Research and Engineering Co.) depositing a radioactive layer on the object or component to be tested. Then heating the labeled object to a temperature below the melting point of the object and of the radioactive layer accelerates diffusion. After diffusion to a suitable depth, the layer can be separated.

The particular application discussed is the corrosion of lead bearings in internal-combustion engines. Previously this involved dismantling the engine and finding the weight loss of the bearing. It is now possible to electroplate a lead-radium D film on the bearing. After diffusion, the bearing can be restored to its original surface by machining or reversing the electroplating process. The bearing is installed in the engine, and the wear is determined by the amount of radioactivity appearing in the oil.

Radioactivity Detector for Bore Holes

U. S. 2,702,352, issued to Shelly Krasnow and Meyer J. Test and assigned to Schlumberger Well Surveying Corp., describes an apparatus for measuring and recording radioactivity in bore holes at various depths. A counting element, e.g., G-M or proportional counter, and amplifier and power supply are contained within a narrow, shock-resistant cartridge capable of being lowered into a bore hole.

The cartridge is suspended in the bore hole by a multiconductor cable that conducts energy into it and re-

ceives responses from it. The cable passes over a wheel that records the depth of the cartridge. The cable can be reeled or unreeled by means of a drum that has slip-ring connections to electrical rectifying, filtering, and recording equipment.

Monoenergetic-Charged-Particle Generator

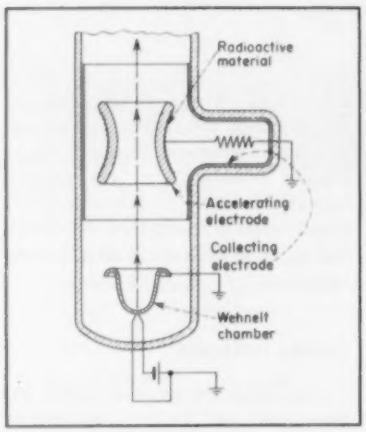


FIG. 2. Charged-particle generator

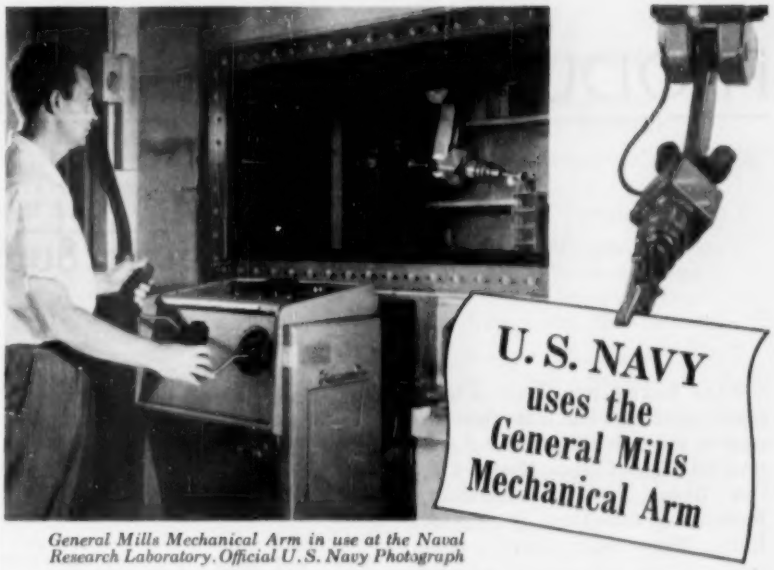
U. S. 2,709,229, issued to Ernest G. Linder (assigned to Radio Corp. of America), describes a monoenergetic-charged-particle generator, utilizing radioisotopes, that can be applied to sterilizing materials (see Fig. 2).

Charged particles emitted by the thermionic cathode are focused into a beam by a Wehnelt cylinder and projected through an accelerating electrode. The outer surface of the latter is coated with a radioactive charged-particle emitter. The desired operating potential and type of radioactive material determine the value of the resistor connecting the accelerating electrode to cathode potential. Accelerator potential is controlled by leakage through the resistor. The radioactive emission is collected on the collecting electrode.

If a beta emitter is used, the accelerating-electrode potential is positive with respect to the cathode. The potential becomes constant when the current through the resistor reaches equilibrium and provides a monoenergetic electron beam. For a positively charged beam, an alpha emitter on the accelerating electrode creates a negative potential.

* * *

These descriptions are based on abstracts furnished by Melvin Nord, Registered Professional Engineer and Patent Attorney, Detroit, Mich.



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PRODUCTS AND MATERIALS

Labeled-Compound Suppliers

When looking for a radioisotope tracer, probably the best place to start is the Oak Ridge catalog and price list (Union Carbide Nuclear Co., Oak Ridge National Laboratory, Radioisotope Sales Dept., Box P, Oak Ridge, Tenn.—price $1.00). Here are listed the radioisotopes sold by ORNL. In general, two forms are available: irradiated units, which are unprocessed irradiated target materials; and processed radioisotopes, which are purified and analyzed solutions.

Prices for these isotopes are the lowest. For example, carrier-free I^{131} has 5–20 mc/ml, analyzes >99%, and costs $0.75/mc. Processed Na^{24} sells for $2.00/mc. Processed C^{14}, sold as barium carbonate, analyzes 0.25–1.5 c/gm of carbon. It sells for $36/mc.

But in many cases, these simple or uncompounded isotopes are not usable for tracing. At this point, the user should consider the availability of the compound he wants from a commercial supplier.

NUCLEONICS quizzed all known suppliers of labeled compounds to assemble these tables. Carbon compounds are shown last. In each category, compounds of medical or biological interest are shown at the end. Each supplier has been assigned a number, shown on p. 81. Suppliers of the same compound are listed in numerical order.

Prices. The price range shown is the high and low quotation for a compound, for the first mc of activity. Usually, orders for more than 1 mc enjoy a sharp reduction in the price/mc. The suppliers welcome the chance to bid on specific quantities of a specific compound. They will also quote on compounds not listed.

Specific activity. Most organic compounds are sold at 1 mc/millimole activity. This is usually variable for special requirements.

AEC Forms Needed

The prospective user must submit form AEC-313 to the AEC, Isotopes Div., Box E, Oak Ridge, Tenn. Purpose is to assure that isotope will be used safely. Upon favorable action, AEC will issue form 374, which licenses the customer to buy the material. The original copy of 374 must accompany all orders, whether to private suppliers or ORNL. Activities greater than 1 μc must be licensed. Two firms supply a variety of C^{14}-labeled compounds at $15 for a 1-μc vial. These can be purchased directly from the California Foundation for Biochemical Research (6) or Fischer Scientific Co. (9) without any AEC license. If minimum activity allowable is raised, then same price will apply to vials containing the new minimum.

Stable Isotopes

Also listed are enriched stable isotopes that can be used as tracers. Stable Isotopes Division of ORNL

Deuterium-Labeled Compounds

Compound	*Minimum order*	*Cost ($/min. order)*	*Suppliers*	*Enrichment at all H_2 positions (%)*
Acetylene	10 l	250	3, 19 (Also 11)	95
Sodium acetate			11 (Also 4)	94 or 99
Methane	5 l	200	3, 19	95
Methanol	1 gm	180	3, 19 (Also 4)	95
Methyl bromide			11	94 or 99
Methyl iodide	3 gm	315	3, 19 (Also 4)	95
Sodium malonate			11	94 or 99
Deuteroparaffin	1 gm	39	3, 19	95
Ethanol	5 gm	350	3, 19	95
Paraldehyde	5 gm	250	3, 19	95
Ethylene bromide	10 gm	225	3, 19 (Also 11)	95
Ethylene			11	94 or 99
Ammonia	5 l	125	3, 19 (Also 4, 11)	95
Ammonium bromide	5 gm	200	3, 19	95
Ammonium hydroxide	10 gm	175	3, 19	95
Ammonium nitrate	10 gm	200	3, 19	95
Ammonium iodide	10 gm	200	3, 19	95
Ammonium phosphate	10 gm	200	3, 19	95
Ammonium sulfate	10 gm	200	3, 19	95
Heavy water*	1 gm	0.59	1 (Also 2, 4)	99.6
Deuterium bromide	5 l	125	3, 19	95
Deuterium chloride	5 l	125	3, 19	95
Deuterium iodide	5 l	125	3, 19	95
Deuterium phosphate	5 gm	125	3, 19	95
Deuterium sulfide	5 l	125	3, 19	95
Sodium hydroxide	5 gm	125	3, 19	95
Sulfuric acid	5 gm	125	3, 19	95

* Water is sterile and pyrogen-free. Also available as physiologic saline. Another heavy-water supplier is Bios Laboratories Inc., 17 W. 60th St., New York 23, N. Y.

NUCLEONICS Special Report

loans enriched stable isotopes of many elements, for a $50 service charge. The ORNL catalog lists these. Stable isotopes listed in this report can be bought commercially.

* * *

Copies of this survey, at 10 cents each, can be obtained from Reprint Department, NUCLEONICS, 330 West 42nd St., New York 36, N. Y.

Carbon-13-Labeled Compounds

Compound	*Atom % C^{13}*	*Price ($/gm C^{13})*	*Quantity containing 1 gm of C^{12} (gm)*	*Supplier*
Barium carbonate	60	210	26	8
Potassium cyanide	60	370	9	8
Methanol	60	360	4	8
Methyl iodide	60	435	19	8

Nitrogen-15-Labeled Compounds

Compound	*Atom % N^{15}*	*Price ($/gm N^{15})*	*Quantity containing 1 gm of N^{15} (gm)*	*Supplier*
Ammonium nitrate	7	140	81	8
(NH_2 radical	30	225	18	8
enriched)	60	335	9	8
Nitric acid	30	270	14	8
(> 2*M*)	60	390	7	8
Potassium nitrate	30	270	23	8
	60	390	11	8
Potassium phthalimide	30	245	42	8
	60	370	21	8

Compound	*Atom % N^{15}*	*Minimum order (gm)*	*Price ($/gm)*	*Supplier*
Nitrogen	60	0.1	590	4
Ammonium chloride	60	0.1	140	4
Ammonium hydroxide*	60	1.0	130	4
Urea-1, 3-N_2^{15}	60	0.1	270	4
Urea-1,3-N_2^{15}			125	1
Glycine			75	1
Barbituric acid-1, 3-N_2^{15}	60	0.5	230	4
Uracil-1, 3-N_2^{15}	30	0.5	290	4
Uramil-1, 3-N_2^{15}	30	0.5	200	4
Uric acid-1, 3-N_2^{15}	30	0.5	260	4

* Supplied as 29% solution; price per gm of solution.

Labeled-Compound Suppliers

1. Abbott Laboratories
   Oak Ridge, Tennessee
2. Atomic Energy of Canada, Ltd.
   Box 93
   Ottawa, Ontario, Canada
3. Baker & Adamson Products
   General Chemicals Division
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   Eastman Organic Chemicals Dept.
   Rochester 3, New York
9. Fischer Scientific Co.
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   Pittsburgh 19, Pa.
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    Box 247
    Montreal, Canada
11. Isotopes Specialties Co.
    703 S. Main St., Burbank, Calif.
12. Merck & Co., Inc., Chemical Div.
    Rahway, New Jersey
13. Nuclear Instrument and Chemical Corp.
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14. Orlando Research, Inc.
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    307 Culver Blvd.,
    Playa Del Rey, Calif.
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17. Schwarz Laboratories, Inc.
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    Mount Vernon, N. Y.
18. Technical Operations, Inc.
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    Arlington 74, Mass.
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    130 High St., Boston 10, Mass.
20. Volk Radiochemical Co.
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Industrial Process Tracers*

Tracer and form	*$/mc*
I^{131} in water (acid stable)	2.25
Co^{60} napthenate	65
Sb^{124} triphenylstibine†	10
I^{131} ethyl iodide	75 + 4/mc
Br^{82} methyl bromide	
I^{131} in particles, stable to 140° F	15 + 2.25/mc
Ir^{192} in same	34 + 1.75/mc
Zr^{95}-Nb^{95} in alumina refractory pellets	40 + 1.75/mc
Co^{60} in beads	20
Se^{46} in particles, stable to 1,400° F	11
Ag^{110} in colloid	12
Co^{60} in colloid	12

* Supplied by Tracerlab, 2419 S. Boulevard, Houston, and other offices.
† Also sold by Isotopes Specialties Corp.

Radioactive Compounds

Compound	*$/mc*	*Suppliers*
CHROMIUM-51		
Sodium chromate	15	1
Sodium chromate		11
Sodium dichromate		11
Chromic acid		11
Chromic chloride	15	1
Chromic oxide		11
Red-cell solution	0.10/cm³	1
COBALT-60		
Vitamin B-12	5–10	1, 12
IODINE-131		
Amyl iodide	135	3, 19
Ethyl iodide	10	2
Methyl iodide	4	11, 15
Iodine	50	3, 4, 19
Iodinated oils		4
Iodoform	80	3, 19
Lauryl iodide	135	3, 19
Sodium iodide		4
Oleic acid		11
Olive oil		11
Stearyl iodide	135	3, 19
Compounds of medical interest		1
PHOSPHOROUS-32		
Chromic phosphate	3.20	1
Disodium phosphate	50	3, 19
Diisopropyl fluorophosphonate	400	18
Phosphorus oxychloride	125	3, 19
Phosphorus tribromide	250	3, 19
Phosphorus trichloride	250	3, 19
Phosphotungstic acid	75	3, 19
Sodium phosphate	4.43	1
Tricresyl phosphate	150	3, 19
Triethyl phosphate	150	3, 19
Triphenyl phosphate	350	3, 19
Sugar phosphates		17
SULFUR-35		
Carbon disulfide	50	3, 19
Dibenzyl disulfide		11
l-Cystine	75	1, 17
Ethyl mercaptan		3, 19
l-Glutathione	150–200	1, 17
l-Methionine	75	1, 17
Penicillin-G	200	1
Phenothiazine		5
Potassium ethyl xanthate	80	3, 19
Potassium thiocyanate	25–75	1, 3, 19
Sodium bisulfite	125–200	3, 19
Sodium sulfite	125	3, 19
Sodium sulfate	5	1
Sodium thiosulfate (inner S)	165	3, 19
(outer S)	80	3, 19
Sulfur dioxide	70	3, 19
Thioacetic acid	110	3, 19
Thioglycolic acid	200	3, 19
Thiourea	50	3, 19
Bacteria and yeast		1, 17
TRITIUM		
Water	1.00–2.50	1, 3, 4, 11, 19
Anthracene	2.00	18
Benzene		4
Methanol		4
Methyl iodide		4
Sodium acetate	2.50	11
MISCELLANEOUS		
Calcium^{45} chloride	15	1
Cesium^{131} chloride	15	1
Cesium^{137} chloride	15	1
Cu^{64} acetate	2	1
Fe^{59} chloride	180	1
Fe^{59}citrate	180	1
Fe^{59} sulfate	180	1
$Gold^{198}$ colloid	1	1
Rb^{86} chloride	15	1
Sodium^{22} chloride	90	1
Sr^{90} chloride	15	1
Sr^{90} oxinate	5	18
Yttrium^{90} chloride	4	1
Y^{90} phosphate		1
Vitamin B-12 (Co^{60})	5–10	1, 12
CARBON-14		
Simple Compounds		
Amorphous C	150–200	3, 8, 11, 13, 19
Barium carbide	100	3, 4, 13, 19
Carbon dioxide	80	4
Carbon monoxide	145	13
CCl_4		3, 19
CARBON-14 (Cont.)		
Cuprous cyanide	210	13
K_2CO_3	105	16
Silicone fluid		1
Sodium carbonate	75–100	3, 4, 8, 13, 14, 16, 19
Sodium cyanide	100–140	3, 4, 11, 14, 16, 19
Hydrocarbons		
Acetylene-1,2	150	11
Alkanes (5–21 C atoms)	550	11
Alkanes	460	13
Aniline-1	600–650	3, 14, 19
Aniline-*u.l.*	700	13
p-aminodimethylaniline	1,500	18
Benzene	600	3, 19
Chlorobenzene-1	800	3, 13, 19
Butane-1	450	11
Ethane-1,2	375–400	11, 14
Ethylene-1,2	200	11
Heptane-4	500	11
Hydroquinone	1,700	18
Isobutane-2	700	11
Methane	325–350	11, 14
Napthalene-1	650	13
Phenol-1	800	3, 19
Propane-2	425–475	11, 14
Toluene-1	500	3, 13, 19
Acetylene and Ethylene Derivatives		
Acetylene-1,2 (2)*	150–165	3, 4, 19
Acetylene-2	150	13
Ethylene-1,2 (2)	245–275	3, 4, 16, 19
Ethylene bromohydrin-1,2 (2)	350	3, 19
Ethylene glycol-1,2	350	3, 11, 19
Ethylene oxide-1,2 (2)	300–400	3, 4, 11, 16, 19
Maleic anhydride-2	800	3, 19
Styrene-8	600	3, 19
Trichloroethylene-1,2 (2)		3, 19
Vinyl-1,2 (2) acetate	600	3, 19
Aldehydes and Ketones		
Acetaldehyde-1,2 (2)		11
Acetaldehyde-1		14
Acetone-1,3 (2)	250–300	8, 11, 13, 14, 16
Acetone-2	225–375	3, 8, 11, 13, 16, 19
Benzaldehyde-*u.l.*	550	13
Cyclohexanone-1		11
Di-n-propyl ketone	425	11
Formaldehyde	250–275	3, 8, 11, 14, 16, 19
Paraformaldehyde	275–350	11, 13

* The number in parenthesis indicates the number of labeled positions per molecule.

Compound	*$/mc*	*Suppliers*
Alcohols and Their Derivatives		
Acetophenone-7	350	3, 19
n-Amyl-1-alcohol	300	3, 19
Benzyl-7-alcohol	250–300	3, 4, 8, 16, 19
Benzyl-7-chloride	350	3, 8, 19
t-Butanol-1	400	11
Cetyl-1 alcohol	420	13
Ethanol-1	250–300	3, 4, 8, 11, 13, 14, 16, 19
Ethanol-2	375–420	4, 8, 13, 16
Ethyl bromide-1,2 (2)	325	11
Ethyl iodide-1	300–350	3, 4, 8, 13, 16, 19
Ethyl iodide-2	425–475	3, 4, 13, 16, 19
Ethyl iodide-1,2 (2)	325	11
Glycerol-1	360–550	11, 13, 16,
Trimethylene glycol-1	350	11
Lauryl-1 alcohol	420	13
Methanol	150–200	3, 4, 8, 11, 13, 14, 16, 19
Methyl chloride	235	3, 19
Methyl iodide	190–325	3, 4, 8, 11, 13, 16, 19
Myristyl-1-alcohol	425	13
1-Naphthal-1	700	13
2-Naphthal-8	725	13
Propyl-1 alcohol	300	8
Propyl iodide-1		16
Propyl iodide-2		16
Isopropyl iodide-1,3	350	13
Isopropyl-1 alcohol	375	11
Isopropyl-1,3 alcohol	325–350	8, 13
Isopropyl-2 alcohol	300	8
Stearyl-1 alcohol	420	13
Acids and Their Derivatives		
Acetic-1 acid	130–135	4, 16
Acetic-2 acid	245	4
Acetic anhydride	125	14
Sodium-1 acetate	105–150	3, 4, 8, 11, 13, 14, 16
Sodium-2 acetate	225–250	3, 4, 8, 11, 13, 16, 19
Sodium acetate-1,2	170	4
Ethyl acetate-1	125–250	3, 14, 16, 19
Bromoacetic-1 acid	225–275	13, 16
Bromoacetic-2 acid	250–300	13, 16
Ethyl bromoacetate-1	180–225	11, 15
Ethyl bromoacetate-2	270–375	11, 16
Methyl bromoacetate-1		3, 19

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Having the appearance of a light meter or camera, it attracts minimum attention from plant personnel during safety checks. The one-piece cast aluminum case is light in weight, but extremely rugged and waterproof. The Geiger tube or battery may be changed in seconds and without tools. Controls are simple, even for non-technical personnel, and the meter is easy to read.

Accuracy is ±10% of full scale on both scales for energies from 50 to 1,200 kev. The Radiameter is useful for monitoring energies as low as 15 kev. In the presence of radiation of high intensity, the instrument does not overload but continues to read off-scale. It can be zeroed even in a strong field. Its fast response permits monitoring x-ray installations turned on only momentarily. Battery life is long—approximately 140 hours.

Available accessories include a probe to multiply sensitivity by 10, a tube to divide sensitivity by 10, an alpha tube, a radium calibration source, a push-button on-off switch, and an attractive leather carrying case. Write for details.

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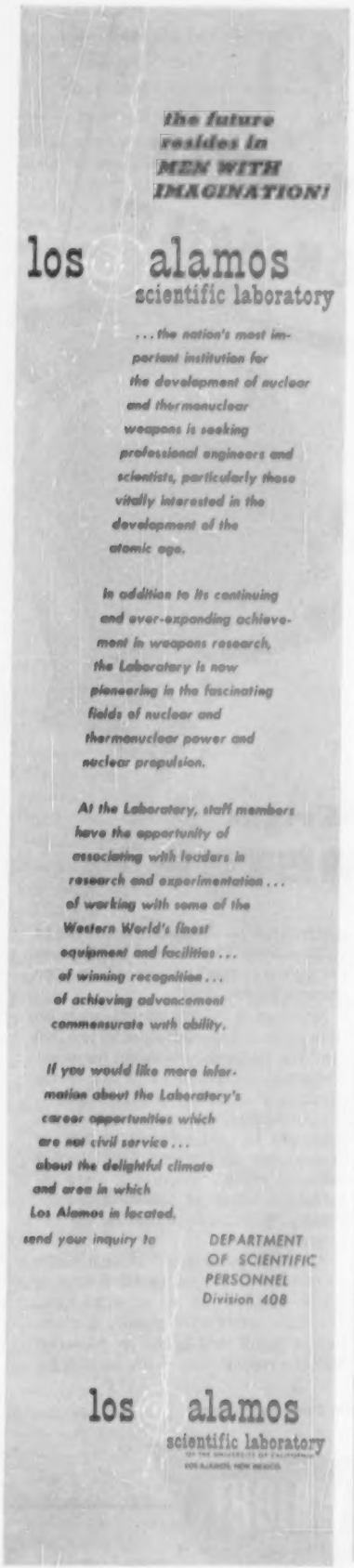
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Compound	*$/mc*	*Suppliers*
Methyl bromoacetate-2	500	13
Sodium bromoacetate-1	275	11
Sodium bromoacetate-2	350	11
Ethyl cyanoacetate-2	375	11
Ethyl cyanoacetate-3	300	11
Methyl cyanoacetate-2	375	13
Sodium cyanoacetate-2	300	13
Chloroacetic-1 acid	225	16
Chloroacetic-2 acid	250	16
Phenyl acetic-1 acid	190	13
Acetonitrile-2	225–250	4, 13, 16
Acetyl bromide-1	195	13
Acetyl bromide-2	340	13
Acetyl chloride-1	125–195	3, 4, 14, 16, 19
Acetyl chloride-2	290	4
Acetylsalicylic acid-carboxyl	375	3, 19
Benzoic acid-7	150–190	3, 4, 8, 11, 13, 16, 19
Benzoic acid-*u.l.*	550	13
Butyric-1 acid	170	16
Sodium butyrate-1	190	8, 13
Caproic-1 acid	170	16
Isocaproic acid	190	13
Caprylic acid-1	170	16
Citric-1,5 acid	625	3, 19
Decanoic-1 acid	190	13
Fumaric-1,4 acid	450	11
Fumaric-2,3 acid	550	11
Sodium formate	100–165	3, 4, 8, 11, 13, 14, 19
Glyceric-3 acid	700	11
Triglyceryl (palmitate-1)	380	13
Triglyceryl (stearate-1)	380	13
Triglyceryl (stearate-2)	650	13
Calcium glycollate-1	150–170	8, 11, 16
Calcium glycollate-2	300–335	8, 11, 16
Hippuric-1 acid	415	16
Iminodi (acetic-2) acid	420	13
Lactic-1 acid	350	16
Lactic-2 acid	350	16
l-Lactic acid-*u.l.*	700	11
Sodium *dl*-lactate-1	380	13
Sodium *dl*-lactate-2	890	13
Zinc *dl*-lactate-2	600	11
Lauric-1 acid	190–250	3, 13, 19
Lincoic-1 acid	295	13

Compound	*$/mc*	*Supplier*
Maleic anhydride-2,3	625	11
Maleic anhydride-1,4	500	11
Maleic anhydride-1	500	13
Calcium malonate-1,3	250	11
Calcium malonate-2	325	11
Silver malonate-1	275	16
Diethyl malonate-1,3	325	11
Diethyl malonate-1	325	16
Diethyl malonate-2	375	3, 11, 13, 19
Margaric acid-1	190	13
Myristic acid-1	190	13
2-Naphthoic acid-carboxyl	190	13
Sodium nonanoate-1	190	13
Sodium octanoate	190	13
Oxalic acid-1,2	185–190	8, 11, 13
Palmatic acid-1	190	3, 11, 13 19
Tripalmitin-carboxyl	625	3, 19
Sodium pentanoate-1	190	13
Barium phosphoglycerate-*u.l.*		13
Sodium propionate-1	190	4, 8, 11, 13
Sodium propionate-2	550–590	8, 13
Sodium pyruvate-1	500	13
Sodium pyruvate-2	650	11, 13
Sodium pyruvate-3	760	11, 13
Phthalic anhydride-7	335	3, 19
p Amino salicylic acid		2
Stearic-1 acid	190–250	3, 11, 13 19
Stearic-2 acid	500	13
Succinic-1 acid	375	13
Succinic-1,4 acid	375	11
Succinic-2 acid	475	3, 19
Succinic-2,3 acid	475	11
Isovaleric-1 acid	250	11
Sodium hydroxyisovalerate-1	600	11
Sodium hydroxyisovalerate-3	600	11
Urea	135	3, 19
Undecanoic acid-1	250	13

Amino Acids and Carbohydrates

These compounds are supplied by 3, 4, 8, 11, 13, 14, 16, 17 and 19.

Steroids

These compounds are supplied by 10 and 13.

INDUSTRY NOTES

▶**Glenco Corp.,** Metuchen, N. J., an associate of Gulton Industries, Inc., is expanding into the nuclear field—first step is an investigation of radiation effects on barium titanate and other dielectrics.

▶**Radiation Instrument Development Laboratory,** nuclear instrument manufacturer, has moved to larger quarters at 5737 S. Halsted St., Chicago 21, Ill.

▶**Thompson Products, Inc.,** Cleveland, Ohio, a principal manufacturer of aircraft, automotive, and electronic products, has set up a nuclear department headed by **Andrew L. Pomeroy.** Serving with him as Manager of Atomic Projects will be **Harry L. Browne,** formerly Director of Facilities Planning at AEC's Sante Fe Operations Office. The new department may acquire small concerns in the nuclear field and will consider joining a nuclear power study group. **George Weil,** U. S. technical director for the Geneva conference, will consult for the new organization.

▶**Tracerlab, Inc.** has appointed **Dr. Charles W. Tittle** as manager of its western division, 2030 Wright Ave., Richmond, Calif. Dr. Tittle had been head of the nuclear physics section of the Gulf Research and Development Corp.

▶**Sensitive Research Instrument Corp.,** electrical instrument manufacturer, has moved to 310 Main St., New Rochelle, N. Y.

▶**Richard C. Cole,** plant manager of the Salt Lake City mill of **Vitro Uranium Co.,** has been made assistant general manager of the company to expand their position in the fields of U processing and refining.

▶**Atomic Instrument Co.,** Cambridge, Mass., has acquired controlling interest in **Kaye Development Co., Inc.,** S. Norwalk, Conn., maker of electronic color evaluation instruments and related detection devices.

▶**Consolidated Engineering Corp.,** Pasadena, Calif., has changed its name to **Consolidated Electrodynamics Corp.**

▶**Everett N. Seider** has been appointed marketing manager of thermal products by ALCO products, Inc., Schenectady, N. Y.

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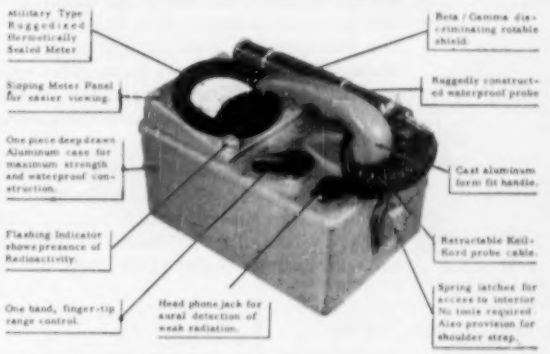
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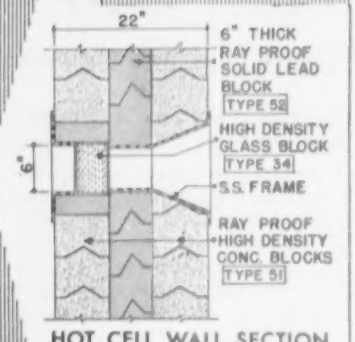

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LETTERS

Swiss Atomic Activity—Corrections

DEAR SIR:

I am terribly unhappy about [a number of errors in] an interview on U. S. bilateral agreements you published in NUCLEONICS under my name (NU, Oct. '55, p. 38). . . . I should like to ask you to publish a rectification.

The Swiss government bought 14 tons of uranium ore from Belgium in 1954. From this ore 10 tons of metal rods were prepared in the U. K. This purchase has nothing to do with the agreement between the U. S. AEC and the Swiss Atomic Energy Commission. The agreement that was signed at the Geneva conference concerned the swimming pool reactor only and especially its enriched fuel elements.

Your correspondent speaks of 34 tons of uranium and states that this could be purchased from the U. S., Belgium and the U. K. thanks only to this agreement.

The Swiss Atomic Energy Commission (SKA) is *purely* a Government agency. It has to advise the Government and promote research in the field of nuclear physics and nuclear energy.

By subsidies, given to the Swiss universities, the SKA has done much to develop nuclear studies in Switzerland; the Commission also has provided the funds necessary to build the accelerators (Van de Graaff, cascade generators, cyclotron, betatrons) installed in Basel, Bern, Geneva and Zurich. At *all* these universities and at the Swiss Federal Institute of Technology excellent research is done with these Government funds.

Your article says: "This agency (SKA) is mainly supported by *industry* . . .", and "The Universities of Basel, Berne, Zurich and Geneva also are teaching one or the other field of nuclear physics."

The "Swiss Reactor Society," founded in March, 1955, takes care of the technical development and of the reactor-building program in this country. In this society, industry and the Government are cooperating. The program of the Reactor Society is financed partly by the Swiss Government and partly by industry. For the time be-

ing, a heavy water research reactor (10,000 kw) and the Geneva swimming pool reactor (modified to be run at 1,000 kw) will be erected at Wurenlingen near Zurich. Four Swiss firms, Brown Boveri, Ciba, Escher Wyss, and Sulzer, with their powerful working group, did efficient and fine planning-work for our pile projects.

In the 18 years we have done research in nuclear physics in Switzerland, a great many nuclear physicists have come out of our Universities and many of them are working in the U. S. and in other foreign countries.

The number 200 you mention of graduate nuclear physicists who came out of the Zurich Institute alone seems exaggerated.

—Dr. P. Scherrer

Physikalisches Institut
der Eidg. Technischen Hochschule
Zurich, Switzerland

Jezebel

Dear Sir:

In connection with the appearance of Jezebel in the October issue (H. C. Paxton, "Critical Assemblies at Los Alamos"), your readers may be interested in learning that she is not the first creature of that name at Los Alamos.

The earlier Jezebel was born in 1944. She was a multiple-channel pulse sorting circuit designed by Ken Greisen and built by William L. Scivally. Because really miniaturized parts were not available in those days, Scivally had to pack 83 GT-size tubes onto a 13 × 17 inch chassis. The circuitry was crammed in layer upon layer until the three-inch deep chassis was completely full.

Two large fans were usually blowing full force upon Jezebel to keep her temperature within reasonable limits. When she was installed in her rack, someone painted her title across her panel in large white letters.

The last time I saw Jezebel was in about 1950 in a storeroom with other experimental equipment which had outlived its usefulness. She was undoubtedly later torn down for the salvage value of her parts.

—Paul Sperling

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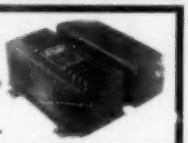
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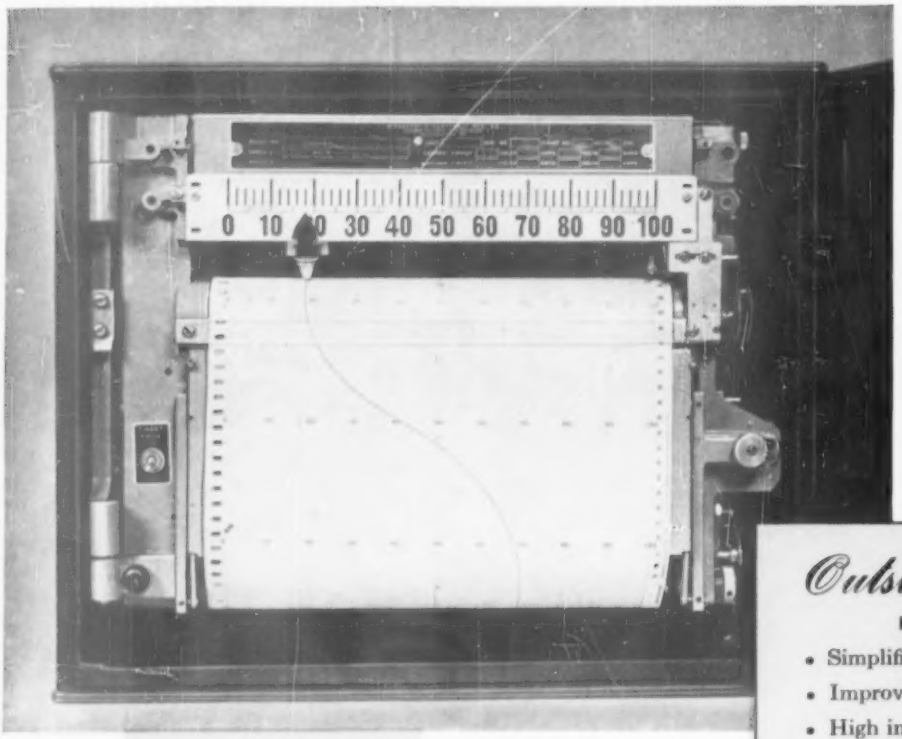

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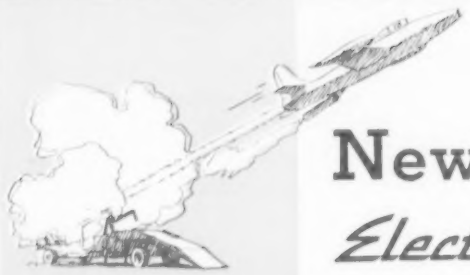

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